NO. 22-1325, -1327

IN THE UNITED STATES COURT OF APPEALS FOR THE FEDERAL CIRCUIT

APPLE INC.,
Appellant

v.

COREPHOTONICS, LTD.,
Cross-Appellant

JOINT APPENDIX

On Appeal from the Patent Trial and Appeal Board in *Inter Partes* Review No. IPR2020-00878

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		4498-4520, 4525-4528
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14	Petitioner's Reply	Appx5318, 5329, 5336-5338, 5342-5352
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UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.,
Petitioner,

v.

COREPHOTONICS, LTD.,
Patent Owner.

IPR2020-00878
Patent 10,330,897 B2

Before BRYAN F. MOORE, MONICA S. ULLAGADDI, and JOHN R. KENNY, *Administrative Patent Judges.*

MOORE, *Administrative Patent Judge*.

JUDGMENT
Final Written Decision
Determining Some Challenged Claims Unpatentable
35 U.S.C. § 318(a)

I. INTRODUCTION

Apple, Inc. ("Petitioner") requested an *inter partes* review ("IPR") of claims 1–6 and 8–30 (the "challenged claims") of U.S. Patent No.

10,330,897 B1 (Ex. 1001, "the '897 patent"). Paper 1 ("Petition" or "Pet."). Corephotonics, Ltd. ("Patent Owner") did not file a Preliminary Response.

On November 3, 2020, we instituted trial. Paper 7 ("Inst. Dec." or "Decision to Institute"). Patent Owner filed a Response. Paper 12 ("PO Resp."). Petitioner filed a Reply. Paper 14 ("Pet. Reply"). Patent Owner filed a Sur-Reply. Paper 19 ("Sur-Reply"). An oral argument was held on June 9, 2021, and a transcript was entered into the record. Paper 28 ("Tr.").

We have jurisdiction to conduct this *inter partes* review under 35 U.S.C. § 6. This Final Written Decision is issued pursuant to 35 U.S.C. § 318(a) and 37 C.F.R. § 42.73. For the reasons discussed herein, we determine that Petitioner has shown, by a preponderance of the evidence, that claims 1, 2, 4–6, 9–15, 17, 18, 20–23, and 25–29 of the '897 patent are unpatentable and that Petitioner has not shown, by a preponderance of the evidence, that claims 3, 8, 16, 19, 24, and 30 of the '897 patent are unpatentable.

II. BACKGROUND

A. The Challenged Patent (Ex. 1001)

The '897 patent issued on June 25, 2019, based on an application filed May 10, 2018, which claimed priority back to a provisional application filed Nov. 19, 2017. Ex. 1001, codes (22), (45), (63). The '897 patent concerns an optical lens assembly with five lens elements. *Id.* at code (57). Figure 1A of the '897 patent is reproduced below.

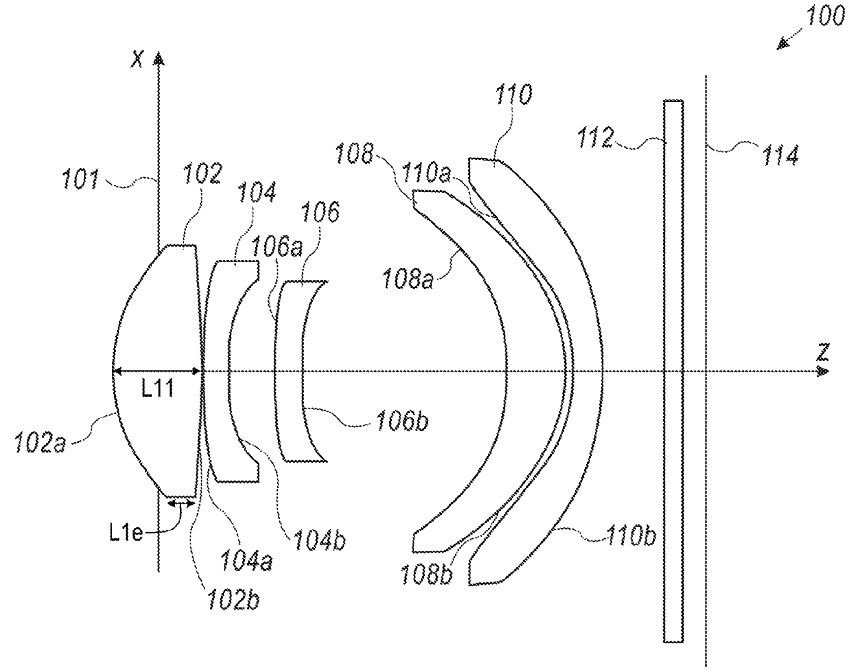


FIG. 1A

Figure 1A of the ’897 patent illustrates an arrangement of lens elements in a first embodiment of an optical lens system.

In order from an object side to an image side, optical lens assembly 100 comprises: optional stop 101; first plastic lens element 102 with positive refractive power having a convex, object-side surface 102*a*; second plastic lens element 104 with negative refractive power having a meniscus, convex, object-side surface 104a, with an image side surface marked 104b; third plastic lens element 106 with negative refractive power having a concave, object-side surface 106a, with an inflection point and a concave image-side surface 106b; fourth plastic lens element 108 with positive refractive power having a positive meniscus with a concave, object-side surface 108a and an image-side surface marked 108b; fifth plastic lens element 110 with negative refractive power having a negative meniscus with a concave, object-side surface 110a and an image-side surface marked 110b. *Id.* at 3:24–41.

In Table 1, reproduced below, the ’897 patent discloses radii of curvature, *R*, for the lens elements, lens element thicknesses and/or distances between each of the lens elements, and a refractive index, *Nd*, for each lens element.

TABLE 1

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	−0.466		2.4
2	L11	1.5800	0.894	1.5345/57.095	2.5
3	L12	−11.2003	0.020		2.4
4	L21	33.8670	0.246	1.63549/23.91	2.2
5	L22	3.2281	0.449		1.9
6	L31	−12.2843	0.290	1.5345/57.095	1.9
7	L32	7.7138	2.020		1.8
8	L41	−2.3755	0.597	1.63549/23.91	3.3
9	L42	−1.8801	0.068		3.6
10	L51	−1.8100	0.293	1.5345/57.095	3.9
11	L52	−5.2768	0.617		4.3
12	Window	Infinite	0.210	1.5168/64.17	3.0
13		Infinite	0.200		3.0

Table 1 of the ’897 patent sets forth optical parameters for the optical lens assembly.

Id. at 4:35–50. The ’897 patent discloses that, in Table 1, reproduced above

> [T]he distances between various elements (and/or surfaces) are marked “Lmn” (where m refers to the lens element number, n=1 refers to the element thickness and n=2 refers to the air gap to the next element) and are measured on the optical axis z, wherein the stop is at z=0. Each number is measured from the previous surface. Thus, the first distance -0.466 mm is measured from the stop to surface 102*a*, **the distance L11 from surface 102*a* to surface 102*b* (i.e. the thickness of first lens element 102)** is 0.894 mm, the gap L12 between surfaces 102*b* and 104*a* is 0.020 mm, the distance L21 between surfaces 104*a* and 104*b* (i.e. thickness d2 of second lens element 104) is 0.246 mm, etc. Also, L21=d_2 and L51=d_5.

Id. at 4:14–50.

Challenged claims 1 and 17 are independent. Challenged claims 2–6 and 8–16 depend directly or indirectly from claim 1 and challenged claims 18–30 depend directly or indirectly from claim 17. Independent claim 1 is reproduced below.

> 1. A lens assembly, comprising:
>
> a plurality of lens elements arranged along an optical axis and spaced apart by respective spaces,
>
> wherein the lens assembly has an effective focal length (EFL), a total track length (TTL) of 6.5 millimeters or less and a ratio TTL/EFL<1.0,
>
> wherein the plurality of lens elements includes, in order from an object side to an image side, a first group comprising lens elements L_{1_1}, L_{1_2} and L_{1_3} with respective focal lengths f_{1_1}, f_{1_2} and f_{1_3} and a second group comprising lens elements L_{2_1} and L_{2_2},
>
> wherein the first and second groups of lens elements are separated by a gap that is larger than twice any other gap between lens elements,
>
> wherein lens element L1_1 has positive refractive power and lens element L_{1_2} has negative refractive power and
>
> wherein lens elements L_{2_1} and L_{2_2} have opposite refractive powers.

Id. at 8:21–36.

B. Asserted Grounds of Unpatentability

Petitioner advances the following challenges supported by the declaration of Dr. José Sasián (Ex. 1003).

Claim(s) Challenged	35 U.S.C. §[1]	Reference(s)/Basis
1, 4, 9–15, 17, 20, 25–29	102	U.S. Patent No. 9,128,267 to Ogino et al. ("Ogino," Ex. 1005)

[1] The Leahy-Smith America Invents Act, Pub. L. No. 112-29, 125 Stat. 284 (September 16, 2011) ("AIA"), included revisions to 35 U.S.C. §§ 102 and 103 that became effective on March 16, 2013. Because the '897 patent issued from an application filed after March 16, 2013, we apply the AIA

Claim(s) Challenged	35 U.S.C. §[1]	Reference(s)/Basis
2, 5, 6, 18, 21–23	103	Ogino and *The Optics of Miniature Digital Cameras* by Jane Bareau et al., SPIE Proceedings Volume 6342, *International Optical Design Conference 2006*; 63421F (2006) ("Bareau", Ex. 1012).
3, 8, 19, 24	103	Ogino, Bareau, and U.S. Patent No. 9,128,267 to Kingslake, *Optics in Photography*, 1992 ("Kingslake," Ex. 1013)
16, 30	103	U.S. Patent No. 10,324,273 to Chen et al. ("Chen," Ex. 1020), and U.S. Patent No. 9,678,310 to Iwasaki et al. ("Iwasaki," Ex. 1009), and *Polymer Optics: A Manufacturer's Perspective on the Factors that Contribute to Successful Programs* by Beich et al. ("Beich," Ex. 1007)

Pet. 8–10.

Patent Owner submits the Declaration of Tom D. Milster, Ph.D. (Ex. 2001) in support of its arguments.

C. Related Matters

The '897 patent is asserted in *Corephotonics Ltd. v. Apple Inc.*, 5-19-cv-04809 (N.D. Cal.) filed August 14, 2019. Pet. 1; Paper 6, 1.

U.S. Patent No. 9,897,712 ("the '712 patent"), 9,402,032 ("the '032 patent"), 9,857,568 ("the '568 patent"), and 10,324,277 ("the '277 patent") are part of a chain of continuity that includes PCT/IB2014/062465, from which the '897 patent also claims priority. This proceeding is related to

versions of the statutory bases for unpatentability. *See* Ex. 1001, codes (22), (60), (63).

IPR2018-01146 (“the ’1146IPR”), an *inter partes* review proceeding instituted based on Petitioner’s challenge to the ’712 patent. The ’1146IPR Final Written Decision was affirmed-in-part and remanded by the Federal Circuit. This proceeding is also related to IPR2018-01140 (“the ’1140IPR”), an *inter partes* review proceeding instituted based on Petitioner’s challenge to the ’032 patent. This proceeding is also related to IPR2019-00030 (“the ’0030IPR”), an *inter partes* review proceeding instituted based on Petitioner’s challenge the ’568 patent. Each of those IPRs resulted in a Final Written Decision and were affirmed by the Federal Circuit on October 25, 2021. Presently pending is IPR2020-00897, an *inter partes* review proceeding based on Petitioner’s challenge to the ’277 patent.

D. Real Parties-in-Interest

Petitioner identifies Apple Inc. as the real party-in-interest. Pet. 1. Patent Owner identifies Corephotonics, Ltd. as the real parties-in-interest. Paper 6, 1.

III. ANALYSIS

A. Principles of Law

Petitioner bears the burden of proving unpatentability of the challenged claims, and the burden of persuasion never shifts to Patent Owner, except in limited circumstances not present here. *Dynamic Drinkware, LLC v. Nat’l Graphics, Inc.*, 800 F.3d 1375, 1378 (Fed. Cir. 2015).

A claim is anticipated if a single prior art reference either expressly or inherently discloses every limitation of the claim. *Orion IP, LLC v. Hyundai Motor Am.*, 605 F.3d 967, 975 (Fed. Cir. 2010). Although the elements must be arranged or combined in the same way as in the claim, “the reference

need not satisfy an *ipsissimis verbis* test," i.e., identity of terminology is not required. *In re Gleave*, 560 F.3d 1331, 1334 (Fed. Cir. 2009) (citing *In re Bond*, 910 F.2d 831, 832–33 (Fed. Cir. 1990)).

A claim is unpatentable under 35 U.S.C. § 103 if the differences between the claimed subject matter and the prior art are such that the subject matter as a whole would have been obvious before the effective filing date of the claimed invention to a person having ordinary skill in the art. *KSR Int'l Co. v. Teleflex, Inc.*, 550 U.S. 398, 406 (2007). The question of obviousness is resolved on the basis of underlying factual determinations, including: (1) the scope and content of the prior art; (2) any differences between the claimed subject matter and the prior art; (3) the level of skill in the art; and (4) when in evidence, objective evidence of non-obviousness, i.e., so-called secondary considerations such as commercial success, long felt but unsolved needs, and failure of others.[2] *Graham v. John Deere Co.*, 383 U.S. 1, 17–18 (1966). The obviousness inquiry further requires an analysis of "whether there was an apparent reason to combine the known elements in the fashion claimed by the patent at issue." *KSR*, 550 U.S. at 418 (citing *In re Kahn*, 441 F.3d 977, 988 (Fed. Cir. 2006) (requiring "articulated reasoning with some rational underpinning to support the legal conclusion of obviousness")).

Thus, to prevail in an *inter partes* review, Petitioner must explain sufficiently how the proposed combinations of prior art would have rendered the challenged claims unpatentable. We analyze the challenges presented in the Petition in accordance with the above-stated principles.

[2] Neither party has argued that secondary considerations or objective evidence of nonobviousness exists. Thus, we do not address secondary considerations or objective evidence of nonobviousness.

B. Claim Construction

Because the Petition was filed after November 13, 2018, we construe the challenged claims using the same claim construction standard that would be used to construe the claims in a civil action under 35 U.S.C. § 282(b). 37 C.F.R. § 42.100(b) (2020).[3] This rule adopts the same claim construction standard used by Article III federal courts, which follow *Phillips v. AWH Corp.*, 415 F.3d 1303 (Fed. Cir. 2005) (en banc), and its progeny. Under this standard, the words of a claim are generally given their "ordinary and customary meaning," which is the meaning the term would have to a person of ordinary skill at the time of the invention, in the context of the entire patent, including the specification. *See Phillips*, 415 F.3d at 1312–13.

Independent claim 1 recites "wherein the lens assembly has an effective focal length (EFL)." Ex. 1001, 8:24–25. Petitioner contends that the term "effective focal length" should be construed as "the focal length of a lens assembly." Pet. 7. This construction coincides with the construction of the same term in the '1140IPR (Paper 10, 10), the '1146IPR (Paper 8, 7–8), and '0030IPR (Paper 32, 8). The '897 specification supports this construction because it is the essentially the same as the specification on which the '1140IPR based the construction of EFL.

Independent claim 1 also recites "wherein the lens assembly has a total track length (TTL) of 6.5 millimeters or less." Ex. 1001, 8:25–26. Petitioner contends that the '897 patent discloses that TTL is the "the length of the optical axis spacing between the object-side surface of the first lens element and one of: an electronic sensor, a film sensor, and an image plane

[3] *See* Changes to the Claim Construction Standard for Interpreting Claims in Trial Proceedings Before the Patent Trial and Appeal Board, 83 Fed. Reg. 51,340 (Oct. 11, 2018) (final rule).

corresponding to either the electronic sensor or [the] film sensor." Pet. 8. This construction coincides with the construction of the same term in the '1140IPR (Paper 10, 10–11), the '1146IPR (Paper 8, 8), and '0030IPR (Paper 32, 14–15). The '897 specification supports this construction because it is the essentially the same as the specification on which the '1140IPR based the construction of TTL.

Patent Owner argues that no "dispute between the parties in this IPR depends on the construction of EFL, TTL, or of any other claim term [and] submits that the Board should refrain from construing any terms in the patent for the purposes of this proceeding." PO Resp. 17. Petitioner does not respond to this argument. *See generally* Pet. Reply. We agree with Patent Owner. If we were to adopt either construction, it would not change the determination made in this Decision.

Thus, we decline to construe any claim terms for purposes of this Final Written Decision. *See Nidec Motor Corp. v. Zhongshan Broad Ocean Motor Co.*, 868 F.3d 1013, 1017 (Fed. Cir. 2017) (quoting *Vivid Techs., Inc. v. Am. Sci. & Eng'g, Inc.*, 200 F.3d 795, 803 (Fed. Cir. 1999)) ("[W]e need only construe terms 'that are in controversy, and only to the extent necessary to resolve the controversy.'").

C. Level of Ordinary Skill in the Art

The level of skill in the art is a factual determination that provides a primary guarantee of objectivity in an obviousness analysis. *Al-Site Corp. v. VSI Int'l Inc.*, 174 F.3d 1308, 1324 (Fed. Cir. 1999) (citing *Graham*, 383 U.S. at 17–18; *Ryko Mfg. Co. v. Nu-Star, Inc.*, 950 F.2d 714, 718 (Fed. Cir. 1991)).

Petitioner argues that one of ordinary skill in the art at the time of the invention of the ’897 patent

> would include someone who had, at the priority date of the ’897 Patent, (i) a Bachelor’s degree in Physics, Optical Sciences, or equivalent training, as well as (ii) approximately three years of experience in designing multi-lens optical systems. Such a person would have had experience in analyzing, tolerancing, adjusting, and optimizing multi-lens systems for manufacturing, and would have been familiar with the specifications of lens systems and their fabrication. In addition, a POSITA [person of ordinary skill in the art] would have known how to use lens design software such as Code V, Oslo, or Zemax, and would have taken a lens design course.

Pet. 6–7 (citing Ex. 1003 ¶¶ 19–20). Patent Owner applied the same level of skill for the purposes of this IPR. PO Resp. 14–15 (citing Ex. 2001 ¶ 19).

We regard Petitioner’s formulation of the level of skill as consistent with the prior art before us. *See Okajima v. Bourdeau*, 261 F.3d 1350, 1355 (Fed. Cir. 2001) (prior art itself may reflect an appropriate level of skill). Therefore, for purposes of this Final Written Decision, we adopt Petitioner’s assessment of the level of skill in the art because it is consistent with the ’897 patent and the asserted prior art, and we apply it in our analysis below.

D. Overview of the Asserted Prior Art

1. Ogino (Ex. 1005)

Ogino concerns an imaging lens. Ex. 1005, code (54). Figure 5 of Ogino is reproduced below.

FIG.5

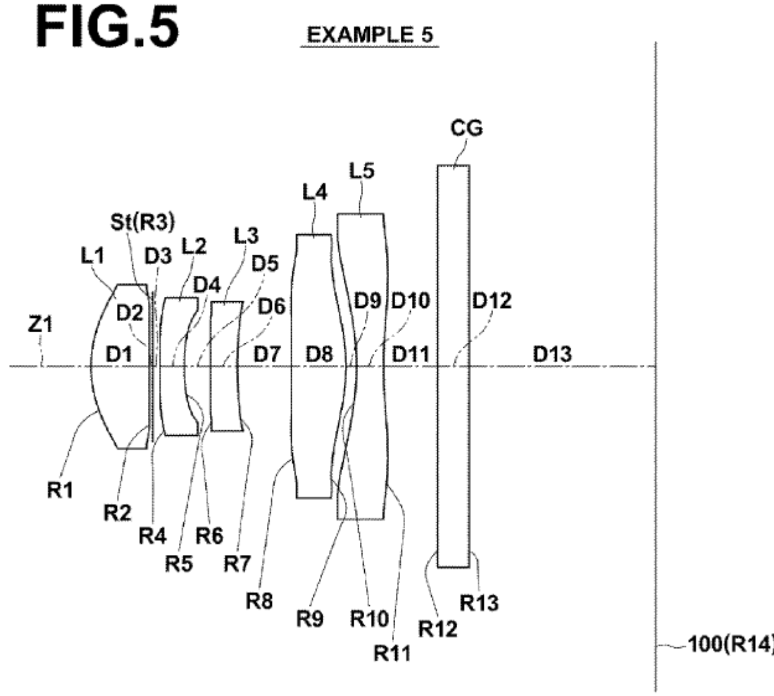


Figure 5 is a lens cross-sectional view illustrating a configuration example of an imaging lens of Ogino

Id. at Fig. 5, 4:5–9. Figure 5, above, shows and embodiment of Ogino including, in order from an object side, five lenses: a first lens L1 that has a positive refractive power and a meniscus shape which is convex toward the object side; a second lens L2 that has a biconcave shape; a third lens L3 that has a meniscus shape which is convex toward the object side; a fourth lens L4 that has a meniscus shape which is convex toward an object side; and a fifth lens L5 that has a negative refractive power and at least one inflection point on an image side surface. *Id.* at 2:4–12.

2. Bareau (Ex. 1012)

Bareau concerns "the design and manufacturing of consumer and commercial imaging systems using lens elements" that have millimeter-scale

diameters. Ex. 1012, 1. Bareau lists an f-number of 2.8 in its "typical lens specifications for a ¼″ sensor format." *Id.* at 3, 4.

3. Kingslake (Ex. 1013)

Kingslake is titled "Optics in Photography." Ex. 1013, Cover. In Chapter 11, titled "The Brightness of Images," Kingslake indicates that "[t]he relation between the aperture of a lens and the brightness of the image produced by it . . . is often misunderstood, yet it is of the greatest importance to the photographer who wishes to make the best use of the equipment." *Id.* at 104. Kingslake then states that "[t]he tremendous efforts of lens designers and manufacturers that have been devoted to the production of lenses of extremely high relative aperture are an indication of the need that exists for brighter images and 'faster' lenses." *Id.*

4. Chen (Ex. 1020)

Chen is directed to "an optical imaging lens set of five lens elements for use in mobile phones, in cameras, in tablet personal computers, or in personal digital assistants (PDA)." Ex. 1020, 1:16–19. Chen's Example 1 is reproduced below:

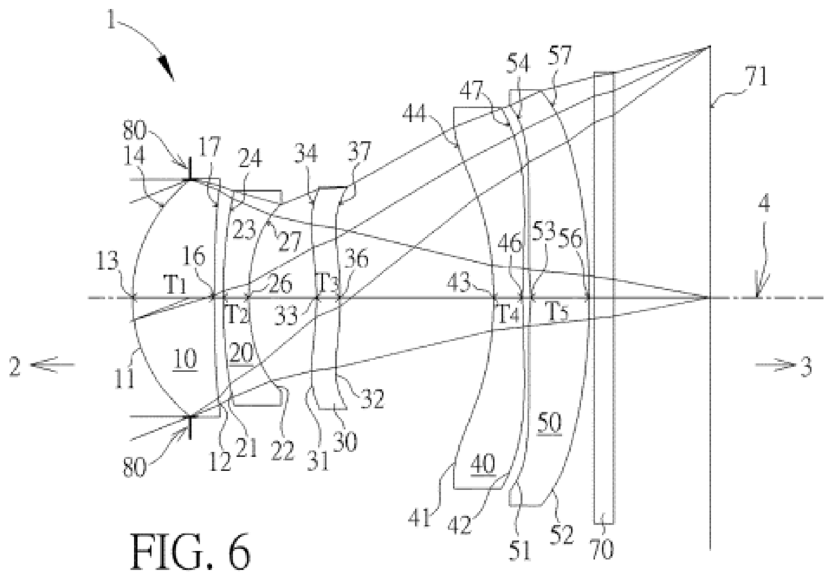


FIG. 6

Figure 6 illustrates an example [Example 1] of the optical imaging lens set

Figure 6, above, shows an "optical imaging lens set 1 of the first example has five lens elements 10 to 50 with refractive power. The optical imaging lens set 1 also has a filter 70, an aperture stop 80, and an image plane 71." *Id.* at 8:55–58. The prescription table describing Example 1 providing the thickness and spacing of each element along the optical axis and the focal length of each lens is provided in Figure 24, reproduced below:

First Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.565	0.855	T_1	1.545	55.987	2.975
		34.464	0.088	G_{12}			
21	Second Lens	6.079	0.264	T_2	1.642	22.409	-4.568
22		1.955	0.704	G_{23}			
31	Third Lens	-3.412	0.249	T_3	1.545	55.987	122.164
32		-3.330	1.598	G_{34}			
41	Fourth Lens	-4.283	0.310	T_4	1.545	55.987	-6.178
42		16.327	0.064	G_{45}			
51	Fifth Lens	-61.049	0.619	T_5	1.642	22.409	15.559
52		-8.680	0.050	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	1.007				
71	Image Plane	INFINITY					

FIG. 24

Figure 24 shows the optical data of the first example of Chen's optical lens set

Figure 24, above, is a table listing the Curvature radius, Aperture Stop Distance Lens Thickness Air Gap, Refractive Index, Abbe Number, and Focal length for the following objects: Aperture Stop, First through Fifth Lens, IR Filter, and Image Plane. According to Chen, Example 1 has a focal length (f) of 6.582 mm, a total track length (TTL) of 6.0187 mm, and an f-number of 2.6614. *See id.* at 10:9–11, Fig. 42 (col. 1). Chen also provides

the sag equation and aspheric coefficients for Example 1. *Id.*, 9:49–67, Fig. 41.

5. Iwasaki (Ex. 1009)

Iwasaki discloses "a fixed focus imaging lens for forming optical images of subjects" that is designed for use in portable devices such as "a digital still camera, a cellular telephone with a built in camera, a PDA (Personal Digital Assistant), a smart phone, a tablet type terminal, and a portable gaming device." Ex. 1009, 1:18–26. Iwasaki's lens system is designed to meet a "demand for miniaturization of the entirety of the photography devices as well as imaging lenses to be mounted thereon" and to meet a "demand for high resolution and high performance of imaging lenses." *Id.* at 1:36–41.

Examples 1 and 2 of Iwasaki maintain this ratio by using a thinner cover glass element of 0.145 mm rather than using 0.210 mm or 0.300 mm thick cover glass used in Examples 3 and 4. *See id.* at Tables 1, 3, 5, 7.

6. Beich (Ex. 1007)

Beich concerns "the process of creating state-of-the-art polymer optics and a review of the cost tradeoffs between design tolerances, production volumes, and mold cavitation." Ex. 1007, 2. Beich discloses design considerations, or "[r]ules of thumb," with respect to shape and tolerances of polymer-based optical devices that drive cost and manufacturability. *Id.* at 7. These considerations include such knowledge as "thicker parts take longer to mold than thinner parts" and "[o]ptics with extremely thick centers and thin edges are very challenging to mold." *Id.*

E. Asserted Anticipation of Claims 1, 4, 9–15, 17, 20, and 25–29 by Ogino

Petitioner contends that claims 1, 4, 9–15, 17, 20, and 25–29 are unpatentable under 35 U.S.C. § 102 as anticipated by Ogino. Pet. 10–40. Patent Owner does not present arguments related to this ground. *See generally* PO Resp. For the reasons that follow, we are persuaded that the evidence supports Petitioner's arguments and thus, Petitioner establishes by a preponderance of the evidence that claims 1, 4, 9–15, 17, 20, and 25–29 are unpatentable under 35 U.S.C. § 102 as anticipated by Ogino.

1. Independent Claim 1

"A lens assembly, comprising: a plurality of lens elements arranged along an optical axis and spaced apart by respective spaces"

Petitioner contends that Ogino discloses this limitation in Ogino's Example 5, shown in Figure 5 reproduced above, which includes lenses L1 to L5 arranged along optical axis Z1, in order from an object side. Pet. 14–15 (citing Ex. 1005, Fig. 5, 5:13–15). Based on the complete record, Petitioner has demonstrated sufficiently that Ogino teaches this limitation, which Patent Owner does not dispute.

"wherein the lens assembly has an effective focal length (EFL)"

Petitioner contends that Ogino teaches for each of its embodiments, that "f is a focal length of a whole system." Pet. 15. (quoting Ex. 1005, 3:16) (citing Ex. 1003, 29). In Table 9, Ogino discloses that the focal length *f* of the entire lens system of Example 5 is provided in Table 9 as *f* = 5.956 mm. *Id.* (quoting Ex. 1005, Table 9) (citing Ex. 1005, 14:47–53). Table 9 of Ogino is reproduced below.

TABLE 9

EXAMPLE 5 f = 5.956, Bf = 2.438, TL = 5.171				
Si	Ri	Di	ndj	νdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	0.506	1.63351	23.63
*9	−1.70702	0.100		
*10	−2.17464	0.253	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

*ASPHERIC SURFACE

Figure 24 shows the optical data of the first example of Ogino's optical lens set

Id. at 21:10–35. Table 9 of Ogino discloses optical parameters for the lens assembly of Example 5, which is depicted in Figure 5. Based on the complete record, Petitioner has demonstrated sufficiently that Ogino teaches this limitation, which Patent Owner does not dispute.

"a total track length (TTL) of 6.5 millimeters or less and a ratio TTL/EFL of less than 1.0"

Petitioner contends that a person of ordinary skill in the art "would have identified the total track length of Example 5 lens apparatus to be the distance between the object-side surface of the first lens L1 and the image plane 100 (R14)." Pet. 16–17 (citing Ex. 1005, Fig. 5; Ex. 1003, 30).

As noted by Petitioner, Ogino explicitly discloses that "the TTL with the cover glass element can be calculated by summing the widths above

labeled D1 to D13" which results in a TTL of 5.273, using the values depicted in Table 9 of Ogino. Ex. 1005, Table 9; *see* Pet. 17–18 (citing in part Ex. 1003, 30–31). Ogino discloses an EFL of 5.956 as depicted in Table 9. Ex. 1005, Table 9; *see* Pet. 17–19 (citing in part Ex. 1003, 30–32).

With Ogino disclosing a TTL of 5.273 and an EFL of 5.956, Ogino also discloses a ratio of TTL/EFL of 0.8853, which is less than 1.0. *See* Pet. 18–19. Based on the complete record, Petitioner has demonstrated sufficiently that Ogino teaches this limitation, which Patent Owner does not dispute.

"wherein the plurality of lens elements includes, in order from an object side to an image side, a first group comprising lens elements L_{1_1}, L_{1_2} and L_{1_3} with respective focal lengths f_{1_1}, f_{1_2} and f_{1_3} and a second group comprising lens elements L_{2_1} and L_{2_2},"

According to Petitioner, Figure 13 of Ogino depicts "Example 5 lens assembly includes a first lens group with three lens elements L1-L3 in order (i.e., L_{1_1}, L_{1_2}, and L_{1_3}) and a second lens group with two lens elements L4-L5 in order (i.e., L_{2_1} and L_{2_2})." Pet. 19–20 (citing Ex. 1003, 33; Ex. 1005, Figs. 5, 13). Petitioner calculates the focal lengths of L_{1_1}, L_{1_2}, and L_{1_3} respectively as 2.068, -3.168, -6.926. *Id.* at 20–21 (citing Ex. 1005, 15:44–48). Based on the complete record, Petitioner has demonstrated sufficiently that Ogino teaches this limitation, which Patent Owner does not dispute.

"wherein the first and second groups of lens elements are separated by a gap that is larger than twice any other gap between lens elements"

Petitioner asserts Figure 5 shows the "gap between the other lens elements are identified as D2+D3 (between L1 and L2), D5 (between L2 and L3), and D9 (between L4 and L5) [and t]he widths of each gap D2+D3 (with

the aperture stop in the middle, which is not a lens element), D5, D7, and D9 are provided in Table 9." Pet. 22–24 (Ex. 1005, Fig. 5, Table 11).

Petitioner further presents, based on this data, calculations that show Ogino's D7 is more than twice as large than the other gaps between lens elements, i.e. D7 (0.506) is more than two times the length of the gaps D2, D3 (0.099), D5 (0.243), and D9 (0.100). *Id.* Based on the complete record, Petitioner has demonstrated sufficiently that Ogino teaches this limitation, which Patent Owner does not dispute.

"wherein lens element L_{1_1} has positive refractive power and lens element L_{1_2} has negative refractive power"

Petitioner contends Ogino discloses this limitation because the optical data for the Example 5 lens assembly shows that the L1 lens element (i.e., L_{1_1}) has positive refractive power and the L2 lens element (i.e., L_{1_2}) has negative refractive power. Pet. 24 (citing Ex. 1003, 37).

Petitioner asserts

> [a person of ordinary skill at the time of the invention] would have recognized that the refractive power of a lens is equal to the inverse of the focal length of the lens: '[t]he practical unit of power is a *dioptre*; **it is the reciprocal of the focal length**, when the focal length is expressed in meters.'

Pet. 24 (quoting Ex. 1010, 159) (alteration in original). Thus, as established above, the L1 lens has a positive focal length of 2.068 mm thereby indicating a positive refractive power and the L2 lens has a negative focal length of -3.168 mm thereby indicating a negative refractive power. *Id.* (citing Ex. 1003, 37). Based on the complete record, Petitioner has demonstrated sufficiently that Ogino teaches this limitation, which Patent Owner does not dispute.

"and wherein lens elements L_{2_1} and L_{2_2} have opposite refractive powers"

Petitioner asserts

> while not given in Ogino, the focal length f4 of the L4 lens can be calculated by inputting the optical data for the lens into the commonly known 'lens maker's equation' for lenses separated by a gap, as stated in Born
>
> $$f = -\frac{n\, r_1\, r_2}{(n-1)[n(r_1 - r_2) - (n-1)t]}$$
>
> where *f* is the focal length of the lens, *n* is the index of refraction, *r*1 and *r*2 are the curvature of the lens's two surfaces, and *t* is the axial thickness of the lens.

Pet. 25.

Petitioner further presents, based on the data in Table 9, calculations that show the L4 lens has a focal length f_4 = 2.7359 mm and the L5 lens has a focal length f_5 = -2.451 mm. *Id.* at 25–27 (citing Ex. 1005, Table 9, 13; Ex. 1003, 40). Thus, because L4 is positive and L5 is negative, they have opposite refractive powers. *Id.* Based on the complete record, Petitioner has demonstrated sufficiently that Ogino teaches this limitation, which Patent Owner does not dispute.

Conclusion

Based on the complete record, and for the reasons explained by Petitioner, we are persuaded that Petitioner has shown by a preponderance of the evidence that Ogino discloses the limitations of claim 1.

2. *Dependent Claims 4, 9–15, 17, 20, 25–29*

Patent Owner does not raise arguments for claims 4, 9–15, 17, 20, and 25–29. We have reviewed Petitioner's arguments and evidence concerning claims 1, 4, 9–15, 17, 20, 25–29, and we adopt them as our own. Pet. 28–40. Thus, based on the complete record, and for the reasons explained by

Petitioner, we are persuaded that Petitioner has also shown by a preponderance of the evidence that these claims are anticipated by Ogino. *See id*.

F. Asserted Obviousness of Claims 2, 5, 6, 18, and 21–23 over Ogino in view of Bareau

Petitioner asserts that the combination of Ogino and Bareau teaches or suggest all the limitations of claims 2, 5, 6, 18, and 21–23, and provides reasoning as to why one of ordinary skill in the art would have been prompted to combine the teachings of these references. Pet. 40–51. For the reasons that follow, we determine that Petitioner has shown persuasively that the combination of Ogino and Bareau would have rendered claims 2, 5, 6, 18, and 21–23 of the ’897 patent obvious.

1. Analysis of Motivation to Combine Ogino and Bareau and the Limitation of "a f-number F#<2.9" and/or "a f-number F#=2.8"

Petitioner's analysis, as supported by the Sasián Declaration, demonstrates where Petitioner contends each element in claims 2, 5, 6, 18, and 21–23 is disclosed in Ogino and Bareau. Pet. 40–51. In particular, Petitioner relies on its anticipation contentions regarding Ogino, discussed above, and adds Bareau to teach the limitation of an f-number less than 2.9, recited in claim 2, and an f-number equal to 2.8, recited in claim 23. *Id.* at 41–49, 51. Our discussion above addresses Petitioner's contentions as to Ogino. *See supra* Section III.E. Accordingly, our discussion here focuses on whether the combination of Ogino and Bareau accounts for the limitations of an f-number less than 2.9 and/or an f-number equal to 2.8.

As to the motivation to combine Ogino and Bareau, Petitioner states

> A POSITA would have found it obvious to modify Ogino's Example 5 lens assembly in view of Bareau's specifications for cell phone camera lenses with an F#=2.8 or less

> for ¼" and smaller image sensors. Such a combination would have been simpl[ly] . . . applying Bareau's specification for a brighter lens system for smaller image sensors, according to known lens design and modification methods (as taught in [Fischer (Ex. 1017)]), to yield a predictable result of Ogino's Example 5 lens assembly likewise supporting an f-number of 2.8 or lower for a small sensor format.

Id. at 41–42 (citing Ex. 1003 ¶ 51; Ex. 1017, 172; Ex. 1024, 1:23–53; Ex. 1012, 3–4). Petitioner relies on Bareau to show that: cell phones having cameras with f-number 2.8 for one quarter inch and smaller sensors were common in 2006; the desire to achieve lower f-numbers was well known because of the need for faster lenses; and "a POSITA therefore would have sought to modify existing lens designs to achieve faster f-numbers like 2.8 while still maintaining a short total track length appropriate for thin cell phone designs." *Id.* at 42 (citing Ex. 1003 ¶ 52; Ex. 1012, 3; Ex. 1013, 104). Petitioner asserts Ogino has examples with an f-number "down to 2.45" and thus "modifying Ogino's Example 5 to have an f-number of 2.8, as taught in Bareau, would have been nothing more than applying Bareau's specification of an F#=2.8 for a ¼" image sensor format according to known lens design methods (as taught in Fischer [Ex. 1017]) to allow Example 5 to likewise better support a ¼" sensor format in a thin cell phone." *Id.* at 43 (citing Ex. 1003 ¶ 53).

Petitioner acknowledges that Bareau has a field of view (FOV) of 60 degrees, associated with a wide lens rather than a telephoto lens, but contends that "that Bareau's specifications for f-number and short TTL would still be highly relevant to incorporating a telephoto lens like Example 5 since TTL dictates the thickness of the cell phone and the f-number indicates how much light reaches the image sensor regardless of a lens's

focal length or FOV." *Id.* (citing Ex. 1003 ¶ 54; Ex. 1005, Figs. 14, 15; Ex. 1012, 3–4; Ex. 1014, Fig. 16, Ex. 1015). Thus, according to Petitioner a person of ordinary skill in the art seeking to create a telephoto lens with a low f-number would have looked to modify Ogino's Example 5. *Id.* (citing Ex. 1003 ¶ 54).

Petitioner, supported by Dr. Sasián, contends one way to modify Example 5 to lower the f-number would be to increase the diameter of one or more lens element surfaces such as the first lens in Example 5 which is the entrance aperture due to the relationship between "f-number, focal length (EFL), and the diameter of the entrance aperture (i.e. the entrance pupil diameter EPD) which controls the amount of light that enters the assembly." *Id.* at 44 (citing Ex. 1003 ¶ 55, Ex. 1016, 59).

According to Petitioner, the lens design arrived at by Dr. Sasián has the following specifications: "EFL=5.648 mm, TTL=5.271 mm, and radii of curvature, spacing, and focal lengths of lens elements L2, L3, L4, and L5 are unchanged and the focal length of L1 is f1=2.0711 similar to f1 unmodified." *Id.* at 45 (citing Ex. 1003 ¶ 56). Petitioner presents Zemax data sheets supporting its contention that its proposed design has "the same structural design (i.e., focal lengths and spacing) and similar performance characteristics when compared to the original Example 5 design." *Id.* (citing Ex. 1003 ¶ 57). Additionally, according to Petitioner, "Example 5 modified for F#=2.8 continues to meet all of the limitations of claim 1 since f1-f5, EFL, TTL, and thicknesses and spacing all still satisfy the respective conditional expressions" of independent claim 1. *Id.* at 46–47 (citing Ex. 1003 ¶ 58). Finally, Petitioner asserts that the declarant for Patent Owner in two related IPRs, IPR2018-01140 and -1146, testified that a person of

ordinary skill in the art would know how to lower the f-number. *Id.* at 47 (citing Ex. 1023, 119:4–22, 121:5–122:13).[4]

Analysis of Patent Owner's Arguments

Patent Owner argues that

> [i]f a POSITA looking at Ogino felt that an f-number of 3.94 was not suitable for their particular application and wanted an f-number of 2.8 instead, that person would naturally look to one of Ogino's other designs, with f-number closer to 2.8, or to one of the hundreds of other miniature lens designs available in the patent literature or in the market. Dr. Sasian provides no explanation for why a POSITA would pick Ogino Example 5, the Ogino lens that is farthest from this desired f-number and modify it dramatically as Dr. Sasian proposes.

PO Resp. 31 (citing Ex. 2001 ¶ 81). This argument does not undermine Petitioner's showing. As explained above, Petitioner cites to Bareau as suggesting lowering the f-number to 2.8. Pet. 41–42. That is, Petitioner has shown an artisan seeking to improve upon or otherwise modify Ogino would have tried to lower the f-number because of the known advantages provided by such a lower f-number. *See id.*

As to the motivation to choose Example 5 versus the other examples in Ogino, the Federal Circuit has found that a person of ordinary skill is not limited to pursuing only the one best option. *PAR Pharm., Inc. v. TWI Pharm., Inc.*, 773 F.3d 1186, 1197–98 (Fed. Cir. 2014) ("Our precedent . . . does not require that the motivation be the best option, only that it be a suitable option from which the prior art did not teach away."); *In re Fulton*, 391 F.3d 1195, 1200 (Fed. Cir. 2004) (holding that "a particular

[4] For example, when asked "[would] a person of ordinary skill in the art be able to reduce an f-number to under 2.9," Dr. Moore testified "Yes." Ex. 1023, 119:19–22.

combination" need not "be the preferred, or the most desirable, combination described in the prior art in order to provide motivation"). Additionally, in response to Patent Owner's argument, Petitioner, in its Reply, contends that Dr. Milster's claim that there were "hundreds" of miniature lens designs did not limit that estimate to telephoto lenses. Pet. Reply 3 (citing Ex. 1025, 78:12–17,[5] Ex. 1037 ¶ 4 (Saisán reply declaration)).

Petitioner also responds, in its Reply, that a person of ordinary skill in the art would have chosen Example 5 because

> Example 5 offers the best telephoto ratio of the Ogino's examples (0.868) which, when considered alone, would have motivated a POSITA to consider it ripe for improvement given its less desirable features, like a higher F-number relative to Ogino's other examples. *See id.*, 16:29-22:35 (Tables 1-11). The low telephoto ratio of Example 5 would also have given a POSITA more flexibility to experiment with the lens design while still maintaining its telephoto character. APPL-1037, ¶ 6.

Id. at 4. To the extent that Petitioner is required to show that a person of ordinary skill in the art would have chosen Example 5 over the other examples in Ogino, we are persuaded that Petitioner has shown this by Petitioner's contention that Example 5 offers the best telephoto ratio above.[6]

Patent Owner also argues "Dr. Sasián's modification to Ogino Example 5 does not satisfy all of the 'typical lens specifications' from

[5] There a appears to be a typographical error and Ex. 1028, 159:25–160:15 (Milster Dep.) appears to be the correct citation.
[6] Petitioner also asserts "The relevance of Ogino to the lenses of the '897 patent is also evidenced by not only their similarities in track length and optical characteristics, but also the fact that Ogino's Example 5 anticipates most of the claims of the '897 patent, which Patent Owner does not dispute." We do not rely on this assertion.

Bareau" because it reduces the full field of view of 40°. PO Resp. 31 (citing Ex. 2001 ¶ 82). Patent Owner asserts that Petitioner needs to explain why the combination "move[s] [] further away" from a specification of Bareau. *Id.* at 31–32. Thus, according to Patent Owner, "nothing cited by Dr. Sasián suggests that an f-number of 2.8 was desirable in the context of a narrower-angle lens." *Id.* We find Petitioner's contentions that the f-number indicates how much light reaches the image sensor regardless of a lens's focal length or FOV (Pet. 43) persuasive, and we find that Patent Owner has not presented sufficient rebuttal why the selection of f-number would be different in narrower-angle lenses; thus, this conclusory argument does not undermine Petitioner's showing. PO Resp. 31; *See generally* Sur-Reply (Patent Owner does not address the field of view of Ogino).

Patent Owner also argues Petitioner has not shown that a person of ordinary skill in the art would have followed Dr. Sasián's approach and made the modification he made. PO Resp. 32–34. Specifically, Patent Owner argues that

> [i]n modifying Ogino Example 5, Dr. Sasian kept the number of lens elements, the powers of the lens elements, their thicknesses, and their spacings unchanged, except for a small change to the thickness of the first lens element. (Ex. 1003, Sasian Decl. at 104; Ex. 2001, Milster Decl., ¶ 84.) He made the small change in thickness of the first lens element, from 0.546 mm (Ex. 1005, Ogino Table 9) to 0.600 mm (Ex. 1003, Sasian Decl. at 107) by hand. (Ex. 2003, Sasian Depo. at 24:14–25:10.) By keeping these parameters (nearly) unchanged, Dr. Sasian ensured that the values of EFL, TTL, lens powers, and lens gaps needed to satisfy other claim elements remained unchanged. (Ex. 2001, Milster Decl., ¶ 84.)

Id. at 32–33. Patent Owner argues that this approach was guided by hindsight rather than the knowledge and motivation of one of ordinary skill

in the art at the time of the invention. *Id.* at 33. Patent Owner points to "vast number of ways" the lens parameters could be varied including 20 different approaches suggested in Dr. Sasián's own design textbook on the subject. *Id.* at 33–34. Patent Owner also suggests a person of ordinary skill would have started with Ogino's Example 6 which has an f-number of 2.64 and a field of view of 59.6° which are more in line with Bareau. *Id.* at 34.

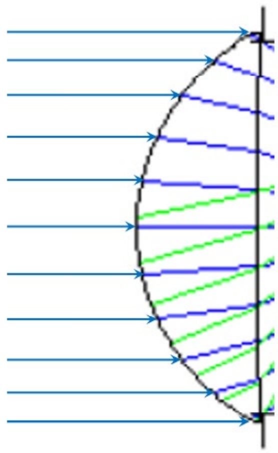
Petitioner argues the approach of making small changes is "precisely" the approach one of ordinary skill would have taken. Pet. Reply 6–7. Petitioner relies on Fischer (Ex. 1017), Kinglake (Ex. 1013) and the opening and reply testimony of Dr. Sasián to support this contention. Pet. Reply 6–7 (citing Ex. 1003, 55, 104; Ex. 1013; Ex. 1017, 168; Ex. 1037 ¶ 11; Ex. 1028, 21:6–18; Ex. 1023, 99:6–18). We credit the testimony of Dr. Sasián on this point. Additionally, Petitioner contends, as discussed above, that "the f-number indicates how much light reaches the image sensor *regardless* of a lens's focal length or FOV." Pet. 43 (citing Ex. 1003 ¶ 54; Ex. 1005, Figs. 14, 15; Ex. 1012, 3–4; Ex. 1014, Fig. 16; Ex. 1015). Patent Owner does not respond to this argument in its Sur-Reply. *See generally* Sur-Reply (Patent Owner does not address this field of view argument).[7] We find that Petitioner has the better position. Petitioner has persuasively explained why one of ordinary skill in the art guided by Bareau would have looked to

[7] Patent Owner's counsel at the hearing asserts that "[t]he F number, the field of view, and the telephoto ratio all depend on the focal length of the lens." Tr. 36. Patent Owner's counsel also argues "because the longer focal length of the narrow-angle lens requires a larger lens element, a larger aperture in order to support the small F number." *Id.* at 362–37. However, these arguments by counsel were not briefed by Patent Owner and are not supported by expert testimony. Therefore, we do not rely on this unsupported attorney argument.

Ogino in order to reduce the f-number below 2.9 and begin with Example 5, then reduce the f-number with a minimum of other changes to the design.

Despite the discussion above, we clarify that we do agree with Patent Owner that a person of ordinary skill in the art would have known that the lenses in Ogino would most likely be made of injection molded plastic. PO Resp. 34–37 (citing Ex. 2001 ¶ 91). We agree with Patent Owner that a person of ordinary skill in the art at the time of the invention would have considered issues of manufacturability in determining the edge thickness and consider oversizing the edges of the lens to deal with this potential problem. *Id.* at 37–46. Finally, we agree a person of ordinary skill in the art at the time of the invention would also have recognized that when designing lens elements for crafting via injection molding, a number of manufacturing realities apply that all promote maximizing the thickness of the lens element at the edge. In particular, the Handbook of Optics (Ex. 1019) states that "Surface-tension effects may play a significant role in the accuracy to which a precision optical surface may be molded. Particularly in areas of the part where the ratio of surface area/volume is locally high (corners, edges) . . . ." PO Resp. 46. Nevertheless, we disagree with Patent Owner regarding the import of one of ordinary skill being aware of manufacturability concerns.

Based on the alleged knowledge of one of ordinary skill discussed above, Patent Owner argues that one of ordinary skill would have believed the edges of the first lens element of Petitioner's proposed lens design would be too thin to be manufacturable. *Id.* at 34. Specifically, Patent Owner, through its declarant Dr. Milster, shows that in order to achieve that f-number in Petitioner's proposed lens design the first lens element would need to be the shape shown below in a drawing reproduced from Dr. Milster's declaration.



In the drawing, reproduced above from Dr. Milster's declaration, representing Dr. Sasián's proposed lens design with an f-number of 2.8, there is a rounded lens surface with blue rays entering from the right and being bent inward as the pass through the lens – the blue rays of this drawing are the rays of the bundle that defines the entrance pupil. *Id.* at 38–39 (citing Ex. 2001 ¶ 96). Based on Dr. Milster's calculations, Patent Owner argues "[t]he resulting shape has a very narrow edge and a large slope at that edge. According to Dr. Milster's calculations, the edge thickness is only 0.0394 mm (or 39.4 microns), and the slope is 58.86°." PO Resp. 40 (citing Ex. 2001 ¶ 98, Appx. § XI.A).

Patent Owner also argues that not only does Dr. Sasián's proposed lens design have thin edges but a commercial lens would be oversized at the edges to accommodate mounting. *Id.* at 41–48. Patent Owner also presents X-Ray CT images of a commercial lens showing that the curved potions of the lens are oversized creating flanges at the edge to accommodate the mounting of the lenses. *Id.* at 41–43. Patent Owner argues that oversizing is necessary because a lens cannot be made with perfectly sharp corners and edges. *Id.* at 43 (citing Ex. 2001 ¶ 103). According to Patent Owner, "[i]n molded lenses, one reason for this is surface tension of the lens material. If

one attempted to inject plastic or glass into a mold with sharp corners such as shown in the Zemax drawing, the liquid would not fill the corners, but would rather form a rounded surface, which would bend light differently than the ideal shape in Zemax." *Id.* Thus, according to Patent Owner, "[a] practical lens design would use an edge shape that permitted oversizing and rounded corners." *Id.* at 46 (citing Ex. 1019, 34.16; Ex. 2001 ¶ 108).

Petitioner points out that claims 2, 5, 6, 18, and 21–23 do not include any manufacturing requirements such as center-to-edge thickness ratio. Pet. Reply 9. Petitioner also points out that "the inclusion of the center-to-edge thickness ratio in claims 16 and 30 and not in any other claims makes it clear that they are additional limitations not required of the other claims of the '897 patent under the doctrine of claim differentiation." *Id.* at 10 (citing *SRI Int'l v. Matsushita Elec. Corp*., 775 F.2d 1107, 1122 (Fed. Cir. 1985) ("It is settled law that when a patent claim does not contain a certain limitation and another claim does, that limitation cannot be read into the former claim in determining either validity or infringement.").

Petitioner also contends that Example 1 of the '897 patent would not meet the manufacturability requirements suggested by Dr. Milster. *Id.* at 17–18 (citing Ex. 1037 ¶ 22; Ex. 1028, 98:24–99:4 (Dr. Milster testified he did not determine whether the lenses in the '897 Specification were manufacturable)); *EPOS Techs. Ltd. v. Pegasus Techs. Ltd.*, 766 F.3d 1338, 1347 (Fed. Cir. 2014) ("[A] claim construction that excludes a preferred embodiment . . . is rarely, if ever correct and would require highly persuasive evidentiary support." (alteration in original)).

We agree that claims 2, 5, 6, 18, and 21–23 do not include any manufacturing requirements such as center-to-edge thickness ratio; therefore

we decline to read a limitation of a manufacturability and/or edge thickness limitation into the claims that do not recite such a requirement.

As to motivation to combine, it is unclear upon which one of the following Patent Owner's argument regarding manufacturability is based: the design proposed by Petitioner being inoperable for its intended purpose, or that there is no reasonable likelihood of success in creating a manufacturable version of the lens design offered by Petitioner, or that a person of ordinary skill in the art simply would not have been motivated to pursue designs that do not meet Beich's rules of thumb for manufacturability. *See* Tr. 55–56. Below, we address each of these possible bases for Patent Owner's arguments.

"The reasonable expectation of success requirement refers to the likelihood of success in combining references to meet the limitations of the *claimed* invention." *See Intelligent Bio-Systems, Inc. v. Illumina Cambridge Ltd.*, 821 F.3d 1359, 1367 (Fed. Cir. 2016) ("[F]ailure to consider the appropriate scope of the . . . patent's claimed invention in evaluating the reasonable expectation of success . . . constitutes a legal error") (emphasis omitted, alteration in original). Because manufacturability concerns regarding edge thickness are not claimed, a person of ordinary skill can have success in making the lens design claimed in claims 2, 5, 6, 18, and 21–23 without regard to manufacturability. Thus, Patent Owner's argument does not undermine Petitioner's showing of reasonable expectation of success.

As to inoperability for its intended purpose, "[i]f references taken in combination would produce a 'seemingly inoperative device,' . . . such references teach away from the combination and thus cannot serve as predicates for a prima facie case of obviousness." *McGinley v. Franklin*

Sports, Inc., 262 F.3d 1339, 1354 (Fed. Cir. 2001). However, a modification to a prior art reference that results in the loss of key functionality can be overcome by evidence that a person of ordinary skill would nevertheless have been motivated to combine references. *In re Urbanski*, 809 F.3d 1237, 1244 (Fed. Cir. 2016). Here, Petitioner presents evidence, including testimony by its declarant, that a person of ordinary skill in the art would have been motivated to make lenses for experimental or research purposes that to do require manufacturing tolerances for edge thickness. Pet. Reply 13–14 (citing Ex. 1037 ¶¶ 16, 17; Ex. 1028, 173:9–11, 25).[8,9]

Petitioner also contends a person of ordinary skill in the art "would have understood these patented lens designs to have usefulness and purpose, and to be physically producible, even if they do not meet the strict large-scale manufacturing considerations argued by Patent Owner. *Id.* at 15 (citing Ex. 1037 ¶ 19). Petitioner contends that Beich suggests that one of ordinary skill would have balanced the manufacturing difficulty of the allegedly thin edges of Petitioner's proposed lens design with the performance achieved by those lenses. *Id.* at 16 (citing Ex. 1007, 1, 7, 9; Ex. 1012, 11).

But it is a commonplace fact that design decisions entail making tradeoffs among multiple objectives. *Allied Erecting and Dismantling Co. v. Genesis Attachments, LLC*, 825 F.3d 1373, 1381 (Fed. Cir. 2016) ("A given

[8] There appears to be a typographical error and the correct citation appears to be Ex. 1028, 182:17–20, 182:9.
[9] Petitioner also asserts that other patents disclose lenses with similar edge thickness. Pet. Reply 14 (citing Exs. 1035, 1036). We do not rely on this evidence.

course of action often has simultaneous advantages and disadvantages, and this does not necessarily obviate motivation to combine.”).

Additionally, Petitioner presents an alternative lens design to show that one of ordinary skill would have been able to create a device that was operable. Pet. Reply 19–21 (citing Ex. 1037 ¶¶ 24–26). Petitioner’s proposed design shows that a design with acceptable edge thickness while still meeting the limitations of claims 2, 5, 6, 18, and 21–23 was within the knowledge of one of ordinary skill in the art. *Id.*

Patent Owner argues that this is a new combination that is untimely and should be disregarded. Sur-Reply 11–12. Specifically, Patent Owner complains “[i]n creating this new lens, Dr. Sasián manually changed the thickness of the first lens element and performed steps in Zemax that turned off vignetting and that caused the location of the image plane to change, along with the conic constant of the first lens surface and 32 higher-order aspheric terms describing the lens surfaces,” all of which would be new purported combinations to which Patent Owner would need to respond. *Id.* at 11. We note that none of the changes Patent Owner discusses, other than the thickness of the first lens, is a limitation of the claims at issue or any other claims of the ’897 patent, nor is the new combination presented as a new ground but rather, as stated above, to show that changing the lens design to meet Patent Owner’s alleged manufacturability concerns was within the knowledge of one of ordinary skill in the art. Pet. Reply 19–21.

Additionally, as to Patent Owner’s assertion that this argument is an improper new argument never before presented by Petitioner, we determine that Petitioner’s additional proposed lens design properly responds to Patent Owner’s arguments that Petitioner’s modification would have rendered Ogino unsatisfactory for its intended purpose or would have frustrated

Petitioner's asserted motivation to combine. *See* 37 C.F.R. § 42.23(b) ("A reply may only respond to arguments raised in the corresponding . . . patent owner response."); *Idemitsu Kosan Co., Ltd. v. SFC Co. Ltd.*, 870 F.3d 1376, 1380–81 (Fed. Cir. 2017) (permitting rebuttal argument from a petitioner in response to a patent owner's argument that a reference taught away from a particular combination, as such argument was "simply the by-product of one party necessarily getting the last word"). Additionally, Patent Owner was given the opportunity to address this alleged new theory in its Sur-Reply.

Therefore, for the reasons above, Petitioner has shown sufficient motivation to combine that is not undermined by Patent Owner's assertions regarding the lack of manufacturability of Petitioner's proposed lens design. That is, Patent Owner's arguments do not undermine Petitioner's showing that the combination of Ogino and Bareau would have taught a person of ordinary skill in the art to create a lens design with an f-number less than 2.9 and/or an f-number equal to 2.8. Additionally, we find that Petitioner has made a sufficient showing that one of ordinary skill in the art would have been motivated to combine Ogino and Bareau in the manner described by Petitioner with a reasonable expectation of success, and that the motivation has sufficient rational underpinning. Pet. 41–47. Below we discuss the remaining limitations of claims 2, 5, 6, 18, and 21–23.

2. Claim 2

"The lens assembly of claim 1, wherein the TTL is equal or smaller than 6.0 mm and the lens assembly has a f-number F#<2.9"

Petitioner relies on its contentions as to how Ogino discloses the limitations of claim 1 discussed above. Pet. 47–48. Petitioner also contends the combination of Ogino and Bareau discloses this limitation in the

modification of Ogino's Example 5 which supports an f-number is 2.8, the TTL is maintained to 5.271 mm as compared to the original TTL of 5.273 mm. *Id.* at 48 (citing Ex. 1003, 62). As explained above, Petitioner has shown sufficiently a motivation to combine Ogino and Bareau so as to modify Ogino's Example 5 to support an f-number is 2.8. Based on the complete record, Petitioner has demonstrated sufficiently that the combination of Ogino and Bareau teaches the limitations of claim 2, which Patent Owner does not dispute except as noted above.

3. Claims 5, 18, and 21–23

Claims 5, 18, and 21–23 depend directly or indirectly from claims 2 and/or 17 and further recite substantially the same limitations as dependent claims 2 and 6. Petitioner refers back to its analysis for claims 1, 2, 6, and 17 (Pet. 49–51), and Patent Owner does not present arguments beyond those discussed above with respect to claim 2. We have reviewed Petitioner's arguments and evidence concerning claims 5, 18, and 21–23 and we adopt them as our own. *Id.* at 49–51. Based on the complete record, and for the reasons explained by Petitioner, we are persuaded that Petitioner has shown by a preponderance of the evidence that the combination of Ogino and Bareau teaches or suggests the limitations of claims 5, 18, and 21–23. *See id.*

4. Claim 6

"The lens assembly of claim 5, wherein lens element L1_1 has a concave image-side surface"

Petitioner relies on Ogino's disclosure of the "L1 lens (i.e., L1_1) in Example 5 which has a meniscus shape which is convex toward the object side." Pet. 50 (Ex. 1005, 13:5–11). Petitioner contends a person of ordinary skill in the art "would have recognized that the description of L1 being

meniscus means that the first lens has a convex object-side surface and a concave image-side surface." *Id.* (citing Ex. 1003, 64). Petitioner contends that this is because meniscus lenses are commonly known to include one convex side and one concave side. *Id.* (citing Ex. 1010, Fig. 4.15). Based on the complete record, Petitioner has demonstrated sufficiently that the combination of Ogino and Bareau teaches the limitations of claim 6, which Patent Owner does not dispute.

G. Asserted Obviousness of Claims 3, 8, 19, and 24 over Ogino, Bareau, and Kingslake

Petitioner asserts that the combination of Ogino, Bareau, and Kingslake teaches or suggests all the limitations of claims 3, 8, 19, 24 and provides reasoning as to why one of ordinary skill in the art would have been prompted to combine the teachings of these references. Pet. 51–61. For the reasons that follow, we determine that Petitioner has not shown persuasively that the combination of Ogino, Bareau, and Kingslake would have rendered claims 3, 8, 19, 24 of the '897 patent obvious.

These claims add two limitations that are not satisfied by the first modification to Ogino used in the ground based on anticipation by Ogino or the ground based obviousness only over Ogino and Bareau: an image-side surface diameter between 2.3 mm and 2.5 mm for the first lens element (claims 3 and 19) and a convex image-side surface (claims 8 and 24). The image-side surface diameter of the first lens element in Petitioner's first modification of Ogino is 2×0.98943 = 1.97886 mm, outside the range required by claims 3 and 19. Ex. 2001 ¶ 126. This image-side surface is also concave, as shown by the positive value of the radius of curvature (252.97534) in Dr. Sasián's lens prescription. Ex. 1003, 107; Ex. 2001 ¶ 126. Dr. Sasián explains how the meniscus lens convex toward the object

side in each of Ogino's examples has a concave image-side surface in his analysis of claim 6. Ex. 1003, 63–66; Ex. 2001 ¶ 128.

Patent Owner asserts "[t]he fact that the first lens element has a concave image-side surface is a feature of every example in Ogino and is described by Ogino as a defining feature of its invention." PO Resp. 56 (citing Ex. 2001 ¶ 126). For example, Ogino explains that its invention uses a first lens that "has a positive refractive power and has a meniscus shape which is convex toward the object side." Ex. 1005, code (57), 13:5–10. Ogino explains its reason for including this feature:

> by making the first lens L1, which is a lens closest to the object, have a positive refractive power and have a meniscus shape which is convex toward the object side in the vicinity of the optical axis, the position of the rear side principal point of the first lens L1 can be set to be close to the object, and thus it is possible to appropriately reduce the total length.

PO Resp. 57 (quoting Ex. 1005, 7:31–37) (emphasis omitted). Petitioner suggests this disclosure would not have discouraged one of ordinary skill from changing the shape of the lens (Pet. Reply 23), however, Patent Owner is not arguing teaching away but rather that Petitioner has failed to present sufficient motivation for the change.

Petitioner also asserts its proposed lens design for this ground changes "[t]he radius of curvature for the image-side surface of L1 [] from concave to convex to allow the L1 lens to better focus incoming light, to provide a thicker edge for easier manufacturing (*see* [Ex. 1007, 7]) while maintaining its original focal length as much as possible." Pet. 60 (citing Ex. 1003, 74–75); Pet. Reply 23. In explaining his method for modifying the lens, Dr. Sasián testifies he "Re-optimize[d the] lens with only lens L1 radii (due to location of the aperture), airspaces, and aspheric coefficients." Ex. 1003,

Appx., 108, Fig. 3D. Petitioner does not explain sufficiently its rationale for modifying Ogino to change the shape of the lens.

Petitioner's cursory reference to better focusing incoming light, providing a thicker edge, or location of the aperture is not sufficient to change the shape of a lens.[10] Petitioner needed to explain sufficiently why the change in shape was required to achieve these benefits as opposed to other possible changes. In its Reply, Petitioner repeats these cursory statements with a slight variation (a "POSITA would have been motivated to change the shape of Ogino's Example 5 first lens to increase the lens diameter to allow more light to pass through the system while maintaining a focal length similar to the original Ogino Example 5 lens assembly"). Pet. Reply 23–24. However, Petitioner still does not explain sufficiently why changing the shape of the lens would have been the method chosen by one of ordinary skill in the art to allow more light in or focus more light. Additionally, Petitioner does not explain sufficiently how the location of the aperture informed this choice.

Petitioner also argues that "the steps Dr. Sasián used to produce the second modified Example 5 lens design . . . are gradual and within the level of a skill of a POSITA." Pet. Reply 24. To the extent that Petitioner wishes to fill a missing limitation with the general knowledge of one of ordinary skill, "the use of common sense [requires] a reasoned explanation that avoids conclusory generalizations." *Arendi S.A.R.L. v. Apple Inc.*, 832 F.3d

[10] Petitioner asserts that in IPR2018-01140 we accepted Dr. Sasián's modification of Ogino's Example 6 lens assembly with the second lens changed from meniscus to biconcave. Pet. Reply 22 (citing Ex. 1032, 44). However, in that case Dr. Sasián relied on a prior art reference and explained the motivation to make the modification. Ex. 1032, 39. He does not do so here.

1355, 1366 (Fed. Cir. 2016). Petitioner's conclusory reference to changes being "gradual" or within the level of skill do not explain sufficiently what about Dr. Sasián's process indicates that one of ordinary skill would be able to take the steps that he did.

Petitioner also asserts, "a POSITA would have been motivated to experiment . . . to see if a smaller f-number would also have been attainable for Example 5. [Ex. 1003], pp.68-69. A *natural* target for further reduction would have been f=2.45, which is the lowest F-number offered in Ogino's examples. *Id.*, p.69." Pet. Reply 24 (emphasis added); *see also id.* at 27–28 ("f=2.45 being a *natural* design goal as provided in Ogino's other embodiment" (emphasis added)). Again, Petitioner does not explain sufficiently why using an f-number of 2.45 would require changing the shape of the first lens. [11]

[11] At the Oral Hearing, Petitioner tried to explain that Dr. Sasián simply ran an optimization and the computer chose to change the shape of the lens. Specifically, Petitioner's counsel argued that

> when Dr. Sasián says that he was starting with Ogino Example 5 at F equals 2.8, he opened the aperture and then he re-optimized the lens only using the L1 radii. So he used the radius -- the radii values on both sides of the first lens and then he allowed the software to optimize it and what that did is that created the convex surface on the image side. The convex surface on the image side is a natural result that the software derived of applying this particular change to this embodiment.
>
> So because it's a natural result of it there's nothing wrong and there's no motivation that needs to be provided specifically for this change. Again, when the change is a natural result of the modification there's no specific argument that needs to be provided -- or reason or motivation that needs to be provided to make that specific change because it's the result of applying the modifications that Dr. Sasián did.

Additionally, at the hearing Petitioner suggested that its reference to "natural" was an inherency argument by citing to *PAR Pharmaceuticals v. TWI Pharmaceuticals*, 773 F.3d at 1195–96. Tr. 53. *PAR* states that "[a] party must[] meet a high standard in order to rely on inherency to establish the existence of a claim limitation in the prior art in an obviousness analysis—the limitation at issue necessarily must be present, or the natural result of the combination of elements explicitly disclosed by the prior art." *PAR Pharms.*, 773 F.3d at 1195–96. We do not determine that Petitioner's passing reference to "natural" raised an inherency argument. However, even if we accepted such an argument, Petitioner has not shown in the Petition that reducing the f-number of Example 1 to 2.45 would "naturally" result in changing the shape of the lens. The Petition states that changing the shape was a choice based on letting more light in the lens. Pet. 60.

Patent Owner also asserts Dr. Sasián made several errors in this calculations concerning this modification to Ogino. PO Resp. 16–17. Petitioner presents evidence that purportedly shows that despite alleged clerical errors in Dr. Sasián's declaration, a person of ordinary skill in the art "would be successful" in making Petitioner's proposed lens design, but this does not explain sufficiently the motivation to make the modification. *See* Pet. Reply 24–28. However, even if we accept that these errors were harmless to Dr. Sasián's overall analysis, the mere fact that the prior art *could* be so modified would not have made the modification obvious unless the prior art suggested the desirability of the modification. *In re Gordon*, 733 F.2d 900, 902 (Fed. Cir. 1984).

Tr. 23. We find no testimony from Dr. Sasián or other evidence in the record to support this attorney argument, therefore we do not rely on it.

Petitioner needed to provide a sufficient rationale for changing a feature of Ogino. Petitioner also argues that "changing the curvature of surfaces within a lens system is a well-known improvement technique that POSITAs regularly consider," and cites Ogino itself as stating that the curvature values can be varied. Pet. Reply 23. Petitioner misses the point. Petitioner must show that one of ordinary skill would have been motivated to make the change it suggests, not just that the art would have allowed that such a change could be made. *See Gordon*, 733 F.2d at 901.

Patent Owner argues

> Dr. Sasian does not explain why ***he*** did it or how he did it in 2020, let alone why a ***POSITA*** would have been motivated to make these changes years earlier. (Ex. 2001, Milster Decl., ¶ 139.) For example, he does not cite to any example of a system with a bi-convex lens that would have motivated the POSITA to try this approach, and he doesn't explain any benefits that flow from this change. (*Id.*) Indeed, the only reason he gives for changing the radii of curvature of the first lens at all (let alone flipping one from a concave positive radius to a convex negative radius) is a vague statement that he did it "due to the location of the aperture." (Ex. 1003, Sasian Decl. at 108; Ex. 2001, Milster Decl., ¶ 139).

PO Resp. 62–63. We agree with Patent Owner. Petitioner does not explain sufficiently why it changed the shape of the lens. Petitioner does not assert that it was because of some suggestion in the art, rather Petitioner relies on unsupported conclusory statements by its declarant.

We have reviewed Petitioner's explanations and supporting evidence regarding dependent claims 3, 8, 19, and 24, and because Petitioner's proposed design with the changed lens shape is used to support its contentions as to claims 3, 8, 19, and 24, we do not find them persuasive in accordance with our above findings. *See* Pet. 51–61. Petitioner, therefore,

has not demonstrated by a preponderance of the evidence that the combined teachings of Ogino, Bareau, and Kingslake would have rendered claims 3, 8, 19, and 24 obvious.

H. Asserted Obviousness of Claims 16 and 30 over Chen, Iwasaki, and Beich

Petitioner asserts that the combination of Chen, Iwasaki, and Beich teaches or suggests all the limitations of claims 16 and 30, and provides reasoning as to why one of ordinary skill in the art would have been prompted to combine the teachings of these references. Pet. 61–84. For the reasons that follow, we determine that Petitioner has not shown persuasively that the combination of Chen, Iwasaki, and Beich would have rendered claims 16 and 30 of the ’897 patent obvious.

Claim 16 - "The lens assembly of claim 18, wherein the lens assembly further includes a ratio between a largest optical axis thickness L11 and a circumferential edge thickness L1e of lens element L1_1 of L11/L1e<3"

Claim 30 - "The lens assembly of claim 18, wherein the lens assembly further includes a ratio between a largest optical axis thickness L11 and a circumferential edge thickness L1e of lens element L1_1 of L11/L1e<3"

Petitioner contends "Chen's Example 1 with a thinner cover glass as taught in Iwasaki shows a TTL of 5.985 mm." Pet. 79. Petitioner also contends Chen's Example 1 has an f-number (F#) of 2.661. *Id.* Petitioner asserts that the Zemax model of Example 1 of Chen shows that "the L1 lens has a center thickness of 0.855 mm (*see* Fig. 24), an edge thickness of 0.293 mm, and a center-to-edge thickness ratio of 2.92. *Id.* at 79 (Ex. 1020, Fig. 24; Ex. 1003, 94–95, Appx., Fig. 4E).

Petitioner notes that Chen does not provide a diameter for its first lens. *Id.* at 80. Because of that fact, Petitioner asserts that "[b]ased on the teaching of Beich, a POSITA would have sought to limit the diameter of the

first lens so that this would be maintained for easier plastic injection molding." *Id.* at 79 (citing Ex. 1007, 7; Ex. 1003, 94). Specifically, according to Petitioner, "a POSITA considering the manufacturability of Chen would have determined the diameter of the first lens such that the lens would cover the aperture (to allow light passing through the aperture to enter the lens system) but would also be easy to manufacture." *Id.* at 80. Thus, according to Petitioner, as "shown in the Zemax calculated model in Dr. Sasián's Appendix, a POSITA would have determined the thickness of the edge of the L1 lens to be 0.293 mm (*see* [Ex. 1003], Appx., Fig. 4E) yielding a center-to-edge thickness ratio of the L1 lens in Chen's Example 1 to be 2.92 (i.e., 0.855/0.293) which is less than the claimed ratio of three and consistent with Beich's teaching. *Id.*, p.95." *Id.* at 80–81.

Patent Owner agrees that Petitioner's choice of a diameter for the first lens results in a center-to-edge thickness of 0.292 mm:

> Dr. Sasian suggests that a POSITA would choose a semi-diameter for this first lens (or at least for its object-side surface) of 1.2375 mm, barely 0.004 mm larger than the semi-diameter of the stop, 1.2333 mm. (Ex. 1003, Sasian Decl. at 115; Ex. 2001, Milster Decl., ¶ 142.) He finds that this lens would have a center-to-edge thickness ratio of 2.92, just under the value of 3 required by claims 16 and 30. (Ex. 2001, Milster Decl., ¶ 142.)
>
> This diameter is essentially the smallest that it could be without disrupting other characteristics of Chen that Dr. Sasian relies upon, such as its f-number. (Ex. 2001, Milster Decl., ¶ 143.)

PO Resp. 64. However, Patent Owner asserts that the diameter chosen could not be much larger or smaller "without reducing the entrance pupil diameter and increasing the f-number" and cannot be made larger than "1.249 mm, approximately 0.012 mm larger (less than 1% larger) than Dr. Sasian

proposes." *Id.* at 64–66 (citing Ex. 2001 ¶¶ 143–145; Ex. 1003, 112). Thus, according to Patent Owner, this violates manufacturing tolerances:

> The Beich paper also says that the tolerance for the diameter of the lens is "± 0.020 mm," and that the displacement between the front surface of the lens and the back surface is "< 0.020 mm." (Ex. 2001, Milster Decl., ¶ 146.) . . . the semi-diameter of the first lens is only 0.004 mm larger than the stop. (Ex. 2001, Milster Decl., ¶ 147.) If the lens is too small by 0.020 mm in diameter (0.010 mm in semi-diameter), this will make the semi-diameter of the first lens ***smaller*** than the semi-diameter of the stop by 6 µm.

Id. at 66. Additionally, according to Patent Owner, having the "first lens smaller than the stop will mean that light will leak and scatter around the lens and cause a haze in the image that is highly undesirable [thus] a POSITA would make the first lens from Chen larger in diameter than Dr. Sasian proposes." *Id.*

Patent Owner asserts "[o]versizing the 1.2374 mm semi-diameter surface by even 1% (far less than is required in practice) would make it 1.2499 mm in semi-diameter and would make the center-to-edge thickness ratio greater than 3. (Ex. 2001, Milster Decl., ¶ 17, Appx. § XI.B.)." *Id.* at 67. We do not rely on oversizing in this Decision. We find the choice to oversize is tradeoff that can be made without undermining the motivation to combine. The mere existence of disadvantages resulting from a modification does not refute the obviousness of the modification, especially when the prior art indicates that the modification also offers an advantage. Tradeoffs regarding features, costs, manufacturability, or the like, do not necessarily prevent the combination. *See Medichem, S.A. v. Rolabo, S.L.*, 437 F.3d 1157, 1165 (Fed. Cir. 2006) ("[A] given course of action often has simultaneous advantages and disadvantages, and this does not

necessarily obviate motivation to combine."); *Winner Int'l Royalty Corp. v. Wang*, 202 F.3d 1340, 1349 n.8 (Fed. Cir. 2000) ("The fact that the motivating benefit comes at the expense of another benefit, however, should not nullify its use as a basis to modify the disclosure of one reference with the teachings of another. Instead, the benefits, both lost and gained, should be weighed against one another."); *Allied*, 825 F.3d at 1381 ("A given course of action often has simultaneous advantages and disadvantages, and this does not necessarily obviate motivation to combine.").

We note that the Federal Circuit specifically found in a context similar to this that oversizing as suggested in the Optic Handbook relied on by Patent Owner does not teach away from using other rules of thumb in Beich. *Corephotonics, Ltd., v. Apple Inc.,* No. 2020-1961, 2021 WL 4944471, at *1 (Fed. Cir. Oct. 25, 2021) ("the *Corephotonics Appeal"*).

As explained with regard to the ground based on Ogino and Bareau, we agree with Patent Owner that a person of ordinary skill in the art at the time of the invention would have considered issues of manufacturability in determining the edge thickness and would have *considered* oversizing the edges of the lens to deal with this potential problem. *See* PO Resp. at 37–46. A person of ordinary skill in the art at the time of the invention would also have recognized that when designing lens elements for crafting via injection molding, a number of manufacturing realities apply that all promote maximizing the thickness of the lens element at the edge. In particular, the Handbook of Optics (Ex. 1019) states that "Surface-tension effects may play a significant role in the accuracy to which a precision optical surface may be molded. Particularly in areas of the part where the ratio of surface area/volume is locally high (corners, edges) . . . ." *Id.* at 46. As we found in

regard to the ground based on Ogino and Bareau, these considerations would not necessarily undermine the motivation to combine.

However, this ground is different from the ground based on Ogino and Bareau in a significant and dispositive way. As to claims 16 and 30 in this ground, Petitioner relies on the same reference Beich–that suggests the design tolerances at issue–to change the diameter of Chen:

> a POSITA looking to manufacture Chen's Example 1 lens system would have understood the benefit of applying the teachings of Beich, thereby resulting in an L1 lens in Chen's Example 1 with a diameter set for manufacturing so that the center-to-edge thickness ratio is maintained at less than 3, as provided for in Chen's original design.

Pet. 70 (emphasis omitted). But Petitioner then contends one of ordinary skill would ignore the design tolerance rule that applies to a change of diameter of the L1 lens, i.e. "[t]he Beich paper also says that the tolerance for the diameter of the lens is '± 0.020 mm,' and that the displacement between the front surface of the lens and the back surface is '< 0.020 mm.'" PO Resp. 66. Although the diameter is not claimed, as discussed above, Patent Owner explains that it is related to the claimed dimensions of the claimed lens such that a change to the diameter affects claim limitations and, in fact, Petitioner changes the diameter for the purpose of meeting other claim limitations. Sur Reply 19–21. We agree with this argument. That is, we determine that a person of ordinary skill in the art would not have been motivated to choose the diameter for Chen that Petitioner suggests upon considering the tolerance rule of Beich.

In response, Petitioner argues that a "lens designer would not have been bound by these specific manufacturing considerations regardless of the purpose of the lens design, especially with the only change being using a

thinner cover glass." Pet. Reply 28. However, Petitioner changes (or sets) the diameter of Chen as well as using a thinner cover glass. Thus, we are not persuaded by this argument. Additionally, Petitioner suggests "Patent Owner complains that the lens design cannot be oversized to meet various alleged manufacturing tolerances for injection molded lenses." *Id.* While Patent Owner does argue that the lens could not be oversized, it also argues that the lens as suggested by Petitioner is unacceptable without oversizing. PO Resp. 67. Specifically, Patent Owner argues "[t]he lens is unacceptable even without taking into account the need to oversize 'considerably beyond the clear apertures.'" *Id.* As noted above, we do not rely on oversizing but rather specifically the tolerance rule of Beich.

Petitioner also argues, in conclusory fashion, that "it would have been obvious for a POSITA to design for different purposes besides ease of manufacturing that still meet the limitations of claims 16 and 30." Pet. Reply 29. We are not persuaded by this late argument. Petitioner relies on manufacturability explicitly as the motivation to combine Chen, Iwasaki, and Beich. Pet. 69 ("[A] POSITA would have set a lens diameter . . . [to] be easier to manufacture."). Petitioner also makes the conclusory assumption that a "POSITA would have had the requisite skill to design a lens system based on Chen's Example 1 that would meet the manufacturing tolerances cited by Patent Owner, if required." Pet. Reply 29.[12] Unlike ground 2 above, Petitioner does not explain sufficiently how its proposed lens design would be changed to take into account the manufacturing tolerance suggested by Beich. Dr. Sasián, in his reply declaration, suggests that "the

[12] We note that Petitioner does not point to other specific rules in Beich or elsewhere that conflict with or undermine Beich's discussion of lens tolerance.

modified Chen Example 1 lens design represents one possible design that meets the limitations of claims 16 and 30" and cites his original declaration at pages 85–99. Ex. 1037 ¶ 37. To the contrary, we do not find at those pages disclosure of any alternative lens design.

Finally, Petitioner suggests, but does not explicitly argue, that the manufacturing tolerances in Beich are not relevant here because the '897 patent does not meet the manufacturing tolerances required by Beich. Pet. Reply 29–30; Ex. 1037 ¶¶ 38–42. Petitioner asserts that the first lens of Example 1 of Chen is the only lens that satisfies the limitation of claims 16 and 30 of L11/L1e<3 with a L11/L1e ratio of 2.99238. Pet. Reply 30. Thus, according to Petitioner, "this lens is not sufficient to meet the claims because it can only be oversized by 0.000759 mm (far less than the 1% larger tolerance allegedly required, Response, p.67) and still be below the claimed ratio because there is no room for 'rounded corners' or 'oversizing considerably beyond the clear apertures.'" *Id.* at 30.

We note that Patent Owner is not arguing that the claims are limited to the tolerances in Beich but rather that a person of ordinary skill in the art "would not have been motivated to make the combination proposed by Dr. Sasián for ground 4." PO Resp. 63. Even if the '897 patent does not take into account Beich's manufacturability considerations, Petitioner itself argues that one of ordinary skill in the art would have taken into account Beich's manufacturability considerations at least as to the center-to-edge thickness ratio. *See* Pet. 69 ("lens manufactures rely on 'rules of thumb,' . . . in manufacturing lens elements to maintain the ratio of center thickness to edge thickness to a value less than three ("< 3:1").") (citing Ex. 1007, 7).

Additionally, Patent Owner's declarant points out several errors in Dr. Sasián's analysis as to whether the examples in the '897 specification meet

the Beich tolerances. Sur-Reply 22–30. We do not need to decide if Dr. Sasián's analysis is sufficiently reliable, because, as explained above, even if we accept Dr. Sasián's analysis as being correct, we are not persuaded that Petitioner's argument that the '897 specification's examples do not meet the manufacturing tolerances would overcome the failure of Petitioner to provide a sufficient rationale to combine Chen with Beich.

Finally, we acknowledge that the Federal Circuit recently upheld our final written decision in IPR2019-00030 finding that the petitioner in that case had shown that Ogino alone and a combination of Ogino and Beich taught a limitation to "a ratio between a largest optical axis thickness L11 and a circumferential edge thickness L1e of the first lens element of L11/L1e<3, as to challenged claim 5 [of the '568 patent]." *Corephotonics Appeal*, at *1. We first note that the *Corephotonics Appeal* had Ogino as a main reference and did not involve Chen or Iwasaki. *Id.* at *1. The *Corephotonics Appeal* did involve Beich's rules of thumb such as Beich's teaching of "center thickness to edge thickness ratio" of <3:1. *Id.* at *3. In fact Patent Owner argued that the "Board did not explain why a relevant artisan would have applied only the center-to-edge thickness ratio rule from Beich (to reduce costs and improve manufacturability), ignoring Beich's diameter-to-thickness ratio rule." *Id.* at *5. However, in the *Corephotonics Appeal* "the L11/L1e ratio that is at issue is solely about the *first* lens element (L1), not the fifth lens element (L5)." *Id.* Here, on the other hand, Patent Owner asserts the same lens to which the center-to-edge thickness ratio rule is being applied is the one that violates the lens tolerance rule at issue in this IPR.

Additionally, the *Corephotonics Appeal* also found that "Nothing in Ogino or Beich 'criticize[s], discredit[s], or otherwise discourage[s]

investigation into, so as to teach away from, selecting the center-to-edge thickness ratio rule of thumb for L1 without modifying other lens elements.'" *Id.* Here, teaching away was not raised or argued but a tolerance directed at the same lens and dimension at issue could be argued to teach away for the modification to Chen.

Finally, in the *Corephotonics Appeal* the Court found patent owner had not shown a "blanket assertion that any willingness to incur higher costs or reduced manufacturability . . . would have undermined (rather than enhanced) the motivation to save costs or improve manufacturability in other ways, such as by following Beich's rule of thumb for the center-to-edge thickness ratio." *Id.* at *6. Here we acknowledge that manufacturability can be a tradeoff but base our decision on the fact that the rule relied on by Patent Owner in this case is closely tied to the rule Petitioner cites for its motivation to modify Chen.

Based on the complete record, Petitioner has not demonstrated sufficiently that the combination of Chen, Iwasaki, and Beich teaches the limitations of claims 16 and 30. As discussed above, we have reviewed Petitioner's explanations and supporting evidence regarding these claims, and we do not find them persuasive in accordance with our above findings. *See* Pet. 61–82. Petitioner, therefore, has not demonstrated by a preponderance of the evidence that the combined teachings of Chen, Iwasaki, and Beich would have rendered claims 16 and 30 obvious.

IV. CONCLUSION

For the foregoing reasons, we determine Petitioner has established by a preponderance of the evidence the unpatentability of claims 1, 2, 4–6 and 9–15, 17, 18, 20–23, 25–29 of the '897 patent and Petitioner has not

established by a preponderance of the evidence the unpatentability of claims 3, 8, 16, 19, 24, 30 of the ’897 patent.[13]

In summary:

Claims	**35 U.S.C. §**	**Reference(s)/ Basis**	**Claim(s) Shown Unpatentable**	**Claim(s) Not Shown Unpatentable**
1, 4, 9–15, 17, 20, 25–29	102(a)	Ogino	1, 4, 9–15, 17, 20, 25–29	
2, 5, 6, 18, 21–23	103(a)	Ogino, Bareau	2, 5, 6, 18, 21–23	
3, 8, 19, 24	103(a)	Ogino, Bareau, Kingslake		3, 8, 19, 24
16, 30	103(a)	Chen, Iwasaki, Beich		16, 30
Overall Outcome			1, 2, 4–6, 9–15, 17, 18, 20–23, 25–29	3, 8, 16, 19, 24, 30

V. ORDER

Accordingly, it is

ORDERED that claims 1, 2, 4–6, 9–15, 17, 18, 20–23, and 25–29 of U.S. Patent No. 10,330,897 B2 are unpatentable and claims 3, 8, 16, 19, 24, and 30 of U.S. Patent No. 10,330,897 B2 are not unpatentable;

[13] Should Patent Owner wish to pursue amendment of the challenged claims in a reissue or reexamination proceeding subsequent to the issuance of this decision, we draw Patent Owner’s attention to the April 2019 Notice Regarding Options for Amendments by Patent Owner Through Reissue or Reexamination During a Pending AIA Trial Proceeding. *See* 84 Fed. Reg. 16,654 (Apr. 22, 2019). If Patent Owner chooses to file a reissue application or a request for reexamination of the challenged patent, we remind Patent Owner of its continuing obligation to notify the Board of any such related matters in updated mandatory notices. *See* 37 C.F.R. §§ 42.8(a)(3), (b)(2).

FURTHER ORDERED that parties to the proceeding seeking judicial review of this Final Written Decision must comply with the notice and service requirements of 37 C.F.R. § 90.2.

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UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.,

Petitioner,

v.

COREPHOTONICS LTD.,

Patent Owner

IPR2020-00878

PETITION FOR *INTER PARTES* REVIEW OF

U.S. PATENT NO. 10,330,897

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APPL-1010	Max Born et al., PRINCIPLES OF OPTICS, 6th Ed. (1980) ("Born")
APPL-1011	Prosecution history of U.S. Patent No. 9,128,267 to Ogino
APPL-1012	Jane Bareau et al., "The optics of miniature digital camera modules," SPIE Proceedings Volume 6342, *International Optical Design Conference 2006*; 63421F (2006) https://doi.org/10.1117/12.692291 ("Bareau")
APPL-1013	Rudolf Kingslake, OPTICS IN PHOTOGRAPHY (1992) ("Kingslake")
APPL-1014	U.S. Patent No. 7,859,588 to Parulski et al. ("Parulski")
APPL-1015	Japanese Patent Pub. No. JP2013106289 to Konno et al. and certified English translation
APPL-1016	Bruce J. Walker, OPTICAL ENGINEERING FUNDAMENTALS (1995)

	("Walker")
APPL-1017	Robert E. Fischer, Optical System Design (2008) ("Fischer")
APPL-1018	Michael P. Schaub, THE DESIGN OF PLASTIC OPTICAL SYSTEMS (2009) ("Schaub")
APPL-1019	Optical Society of America, HANDBOOK OF OPTICS, vol. II 2nd ed. (1995) ("Handbook of Optics")
APPL-1020	U.S. Patent No. 10,324,273 to Chen et al. ("Chen")
APPL-1021	U.S. Patent No. 9,857,568
APPL-1022	U.S. Patent No. 9,568,712
APPL-1023	Deposition Transcript of Duncan Moore, Ph.D. in IPR2018-01140
APPL-1024	U.S. Patent No. 7,321,475 to Wang et al.
APPL-1025	Greg Hollows et al., "Matching lenses and sensors", Vision Systems design (March 2009)
APPL-1026	Prosecution history of U.S. Patent No. 9,678,310 to Iwasaki et al.
APPL-1027	Email from Patent Owner's counsel authorizing electronic service

I. INTRODUCTION

U.S. Patent No. 10,330,897 ("the '897 Patent," APPL-1001) is generally directed to "[a]n optical lens assembly [that] includes five lens elements and provides a TTL/EFL<1.0." APPL-1001, Abstract. This Petition, along with the cited evidence, demonstrates that claims 1-6 and 8-30 of the '897 Patent ("the challenged claims") are either anticipated or rendered obvious by the prior art. Apple Inc. ("Petitioner") therefore respectfully requests that these claims be found unpatentable and cancelled.

II. MANDATORY NOTICES

A. Real Party-in-Interest

The real party-in-interest is Apple Inc.

B. Related Matters

As of the filing date of this Petition and to the best knowledge of the Petitioner, the '897 Patent has been asserted in *Corephotonics, Ltd. v. Apple Inc.*, Case No. 5-19-cv-04809 (N.D. Cal. filed Aug. 14, 2019).

C. Lead and Back-up Counsel and Service Information

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Please address all correspondence to lead and back-up counsel. Petitioner consents to electronic service via email.

III. GROUNDS FOR STANDING

Petitioner certifies that the ’897 Patent is eligible for *inter partes* review and that Petitioner is not barred or estopped from requesting *inter partes* review challenging the patent claims on the grounds identified in this Petition. Petitioner was served with a complaint asserting infringement of the ’897 Patent on August 19, 2019 and has not filed a civil action challenging the validity of any claim.

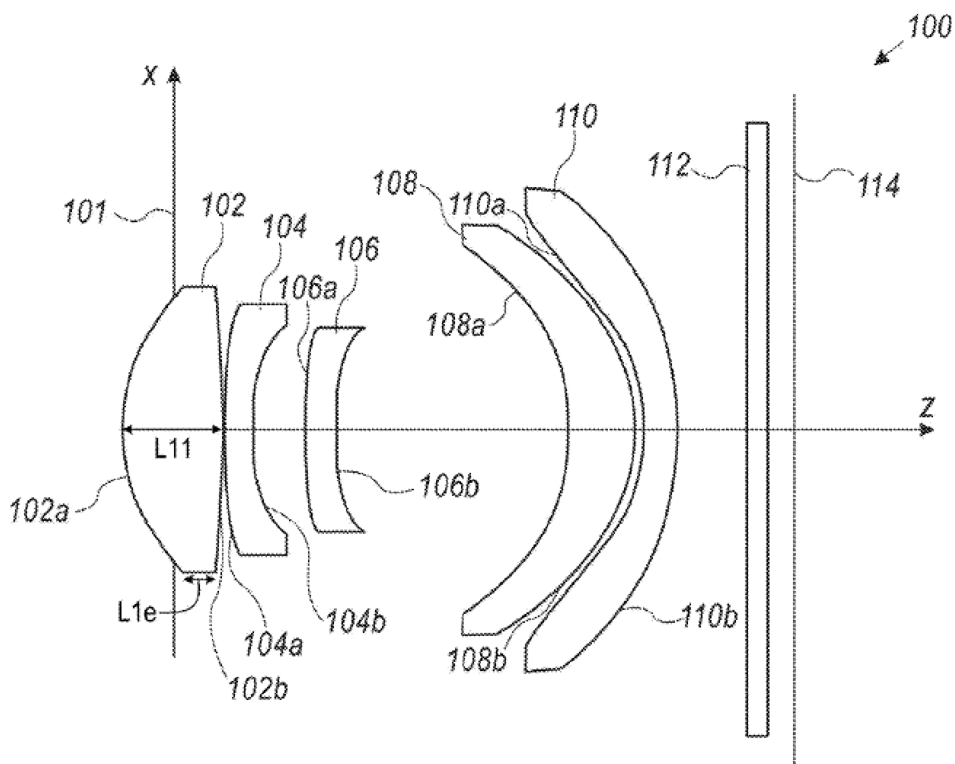
IV. NOTE REGARDING PAGE CITATIONS AND EMPHASIS

Petitioner’s citations to APPL-1002, -1011, -1025, and -1026 use the page numbers added for compliance with 37 C.F.R. § 42.63(d)(2)(ii). Petitioner’s citations to the remaining exhibits use reference numbering in their original publication. All **<u>bold underline</u>** emphasis in any quoted material has been added.

V. OVERVIEW OF THE '897 PATENT

A. Summary of the Patent

The '897 Patent is directed to "[a]n optical lens assembly [that] includes five lens elements and provides a TTL/EFL<1.0." APPL-1001, Abstract. The ratio of TTL ("total track length") over EFL ("effective focal length") being less than one indicates a telephoto lens system. *See* APPL-1006, p.169. According to the Applicant, the lens system in the '897 Patent is allegedly the answer to the need for good quality imaging and a small total track length. *See* APPL-1001, 1:43-50. An example of the claimed lens system is provided below:



APPL-1001, Fig. 1A.

For each embodiment, the ’897 Patent includes optical data for each lens element, such as radius of curvature (“R”) and aspheric coefficients that describe the surface of each aspheric lens element. *See id.*, Tables 1-6. The ’897 Patent also includes the so-called surface “sag” equation, which is the standardized equation used for mathematically representing the surfaces of aspheric lens elements. *Id.*, 4:1-14. The ’897 Patent’s explanation of the sag equation is as follows:

> Detailed optical data is given in Table 1, and the aspheric surface data is given in Table 2, wherein the units of the radius of curvature (R), lens element thickness and/or distances between elements along the optical axis and diameter are expressed in mm, “Nd” is the refraction index. The equation of the aspheric surface profiles is expressed by:
>
> $$z = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + \alpha_1 r^2 + \alpha_2 r^4 + \alpha_3 r^6 + \alpha_4 r^8 + \alpha_5 r^{10} + \alpha_6 r^{12} + \alpha_8 r^{14}$$
>
> where r is distance from (and perpendicular to) the optical axis, k is the conic coefficient, c=l/R where R is the radius of curvature, and α_i are coefficients given in Table 2.

Id.

As discussed below, none of these characteristics were new. Prior to July 4, 2013, multi-lens assemblies for cell phones were well known, including telephoto lens assemblies. *See* APPL-1006, pp.169-182; APPL-1005, Fig. 5; APPL-1003, ¶32. For example, Ogino (APPL-1005) and Chen (APPL-1020) both teach multi-

lens systems for cell phones with a TTL to EFL ratio of less than one. APPL-1003, ¶32. Accordingly, the disclosures provided herein either anticipate or render obvious the claims challenged in this Petition.

B. Priority Date of the ’897 Patent

The ’897 Patent is a continuation of a string of patent applications claiming priority to Provisional Application No. 61/842,987 filed on July 4, 2013. *See* APPL-1001. The subject matter of claims 16 and 30, though, was not included in this provisional application, but instead was first added in U.S. Patent No. 9,857,568 filed on January 30, 2017 as a <u>continuation-in-part</u> of U.S. Patent No. 9,568,712. *Compare* APPL-1021 *with* APPL-1022. This is clearly the case since all of the continuation applications filed prior to the ’568 Patent make no mention of a center thickness L11, an edge thickness L1e, or the need to maintain a center-to-edge thickness ratio (L11/L1e) of less than 3.0. APPL-1003, ¶33. Also, a POSITA would not have concluded, based on the embodiments included in the original application, that the Applicant was in possession of any “alleged” invention, in having a center-to-edge thickness ratio of less than three, prior to the specification filed with the ’568 Patent. *Id.*

Consequently, the priority date of claims 16 and 30 is January 30, 2017, the filing date of the ’568 Patent. *See also LizardTech, Inc. v. Earth Resource Mapping, Inc.*, 424 F.3d 1336, 1343-47 (Fed. Cir. 2005) (finding a claim

unsupported due to a lack of written description needed to show that the applicant was in possession of the invention).

C. Prosecution History

The ’897 Patent issued on June 25, 2019 from U.S Patent Application No. 15/976,391 (“the ’391 application”) filed on May 10, 2018. *See* APPL-1001. The ’391 application was filed with the 30 claims issued in the ’897 Patent with one substantive amendment added during prosecution to require a glass plate between the fifth lens element and the image plane. *See* APPL-1002, p.254. The ’391 application was allowed on March 4, 2019 with no statement from the Examiner as to patentability. *See id.*, pp.34-35. The prior art presented in this Petition was not applied by the Examiner and was not used as a basis for allowing the claims.

VI. LEVEL OF ORDINARY SKILL IN THE ART

The level of ordinary skill in the art may be reflected by the prior art of record. *See Okajima v. Bourdeau*, 261 F.3d 1350, 1355 (Fed. Cir. 2001); *In re GPAC Inc*., 57 F.3d 1573, 1579 (Fed. Cir. 1995). Here, a person of ordinary skill in the art (“POSITA”) would include someone who had, at the priority date of the ‘897 Patent (i) a Bachelor’s degree in Physics, Optical Sciences, or equivalent training, as well as (ii) approximately three years of experience in designing multi-lens optical systems. APPL-1003, ¶19. Such a person would have had experience in analyzing, tolerancing, adjusting, and optimizing multi-lens systems for

manufacturing, and would have been familiar with the specifications of lens systems. In addition, a POSITA would have known how to use lens design software such as Code V, Oslo, or Zemax, and would have taken a lens design course. *Id.* Lack of work experience can be remedied by additional education, and vice versa. *Id.*, ¶20.

VII. CLAIM CONSTRUCTION

The challenged claims of the ’897 Patent are construed herein “using the same claim construction standard that would be used to construe the claim in a civil action under 35 U.S.C. § 282(b).” 37 C.F.R. §42.100(b) (Nov. 13, 2018). For terms not addressed below, Petitioner submits that no specific construction is necessary for this proceeding.[1]

In IPR2018-01140[2], the Board construed the following terms as indicated below:

[1] Petitioner does not concede that any term not construed herein meets the statutory requirements of 35 U.S.C. § 112.

[2] IPR2018-01140 is directed to U.S. Pat. No. 9,402,032. The Board entered the same constructions in IPR2018-01146 directed to U.S. Pat. No. 9,568,712. Both patents belong to the same family as the ’897 Patent and are currently appealed on other grounds.

- **<u>Effective Focal Length (EFL):</u>** "*the focal length of a lens assembly*."
- **<u>Total Track Length (TTL):</u>** "*the length of the optical axis spacing between the object-side surface of the first lens element and one of: an electronic sensor, a film sensor, and an image plane corresponding to either the electronic sensor or a film sensor*."

See IPR2018-01140, Paper 37, pp.10-18. The analysis below relies on these constructions which are sufficient here for showing how the challenged claims are unpatentable by prior art.

VIII. RELIEF REQUESTED AND THE REASONS FOR THE REQUESTED RELIEF

Petitioner asks that the Board review the accompanying prior art and analysis, institute a trial for *inter partes* review of claims 1-6 and 8-30 of the ’897 Patent and cancel these claims. As explained below and in the declaration of Petitioner’s expert, Dr. José Sasián, the concepts described and claimed in the ’897 Patent were not new. This Petition explains where each element of the challenged claims is found in the prior art and why the claims would have been either anticipated or obvious to a person of ordinary skill in the art (“POSITA”) before the earliest claimed priority date of each claim of the ’897 Patent.

IX. IDENTIFICATION OF HOW THE CLAIMS ARE UNPATENTABLE

A. Challenged Claims

Claims 1-6 and 8-30 of the ’897 Patent are challenged in this petition.

B. Statutory Grounds for Challenge

Ground 1: Claims 1, 4, 9-15, 17, 20, and 25-29 are anticipated under 35 U.S.C § 102(a)(2) by U.S. Patent No. 9,128,267 to Ogino (APPL-1005, "Ogino"). Ogino was filed on March 26, 2014 and issued on September 8, 2015. Ogino claims priority to Japanese Application No. 2013-072282 that was filed on March 29, 2013. As observed in Ogino's file history (APPL-1011), the application was filed in English (*see id.*, pp.209-87) and a certified copy of the Japanese application was received by the Patent Office (*see id.*, pp.146-85). Accordingly, Ogino's effective filing date under § 102(a)(2) is the filing date of the Japanese application filed on March 29, 2013. Thus, Ogino is prior art under 35 U.S.C. § 102(a)(2).

Ground 2: Claims 2, 5, 6, 18, and 21-23 are obvious under 35 U.S.C. § 103 over Ogino in view of Jane Bareau et al., "The optics of miniature digital camera modules" (2006) (APPL-1012, "Bareau"). Bareau was both presented publicly and published in 2006 (*see* APPL-1003, ¶47) and is prior art under 35 U.S.C. § 102(a)(1).

Ground 3: Claims 3, 8, 19, and 24 are obvious under 35 U.S.C. § 103 over Ogino in view of Bareau, further in view of Kingslake (APPL-1013, "Kingslake"). Kinglake published in 1992 and is prior art under 35 U.S.C. § 102(a)(1).

Ground 4: Claims 16 and 30 are obvious under 35 U.S.C. § 103 over U.S. Patent No. 10,324,273 to Chen et. al (APPL-1020, "Chen") in view of U.S. Patent No. 9,678,310 to Iwasaki et al. (APPL-1009, "Iwasaki"), further in view of William S. Beich et al., "Polymer Optics: A manufacturer's perspective on the factors that contribute to successful programs" ("Beich," APPL-1007). Chen was filed on October 16, 2016 and Iwasaki was filed on September 17, 2015. Both references are thus prior art to claims 16 and 30 under at least 35 U.S.C. § 102(a)(2).

Iwasaki also claims priority to Japanese Application No. 2013-061647 that was filed on March 25, 2013. As observed in Iwasaki's file history (APPL-1026), the application was filed in English (*see id.*, pp.323-63) and a certified copy of the Japanese application was received by the Patent Office (*id.*, pp.127-57). Accordingly, Iwasaki's effective filing date under § 102(a)(2) is the filing date of the Japanese application filed on March 25, 2013, before the earliest claimed priority of the '897 Patent.

Beich was published in 2010 and is prior art under 35 U.S.C. § 102(a)(1). *See* APPL-1007, p.1. Beich was presented as prior art against the related '568 Patent (*see* IPR2019-00030, Paper 32 (Final Written Decision)) where Beich's availability as prior art was undisputed.

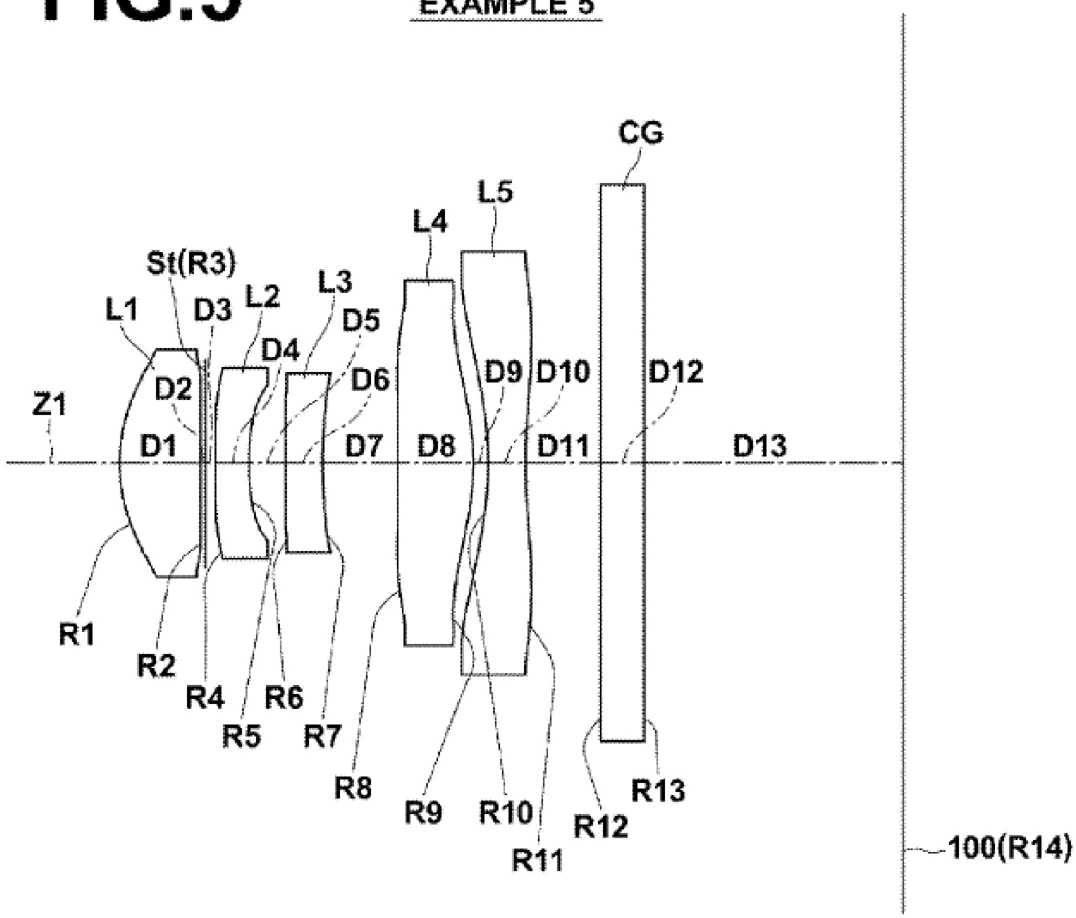
C. Ground 1: Claims 1, 4, 9-15, 17, 20, and 25-29 are anticipated under 35 U.S.C. § 102(a)(2) by Ogino.

1. Summary of Ogino

Similar to the lens system described in the ’897 Patent, Ogino discloses a five-lens system designed “to enhance the resolution and performance of the imaging lens” for portable devices such as “a smartphone, a tablet terminal, and a mobile game machine” among other devices. APPL-1005, 1:11-16, 1:30-31. Ogino’s Example 5 embodiment is particularly relevant to the claims in the ’897 Patent, and is provided below:

FIG.5

EXAMPLE 5



Id., Fig. 5. In Example 5, lens elements L1-L5 are arranged in order along the optical axis. *Id.*, 13:4-5. Optical member CG "may be disposed between the fifth lens L5 and the imaging device 100 …." *Id.*, 5:55-57. The CG member is optional and serves to "protect an imaging surface and an infrared ray cut filter …." *Id.*, 5:58-60.

The Example 5 lens system is described in detail by the prescription data in Table 9, provided below:

TABLE 9

EXAMPLE 5
f = 5.956, Bf = 2.438, TL = 5.171

Si	Ri	Di	ndj	vdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	0.506	1.63351	23.63
*9	−1.70702	0.100		
*10	−2.17464	0.253	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

*ASPHERIC SURFACE

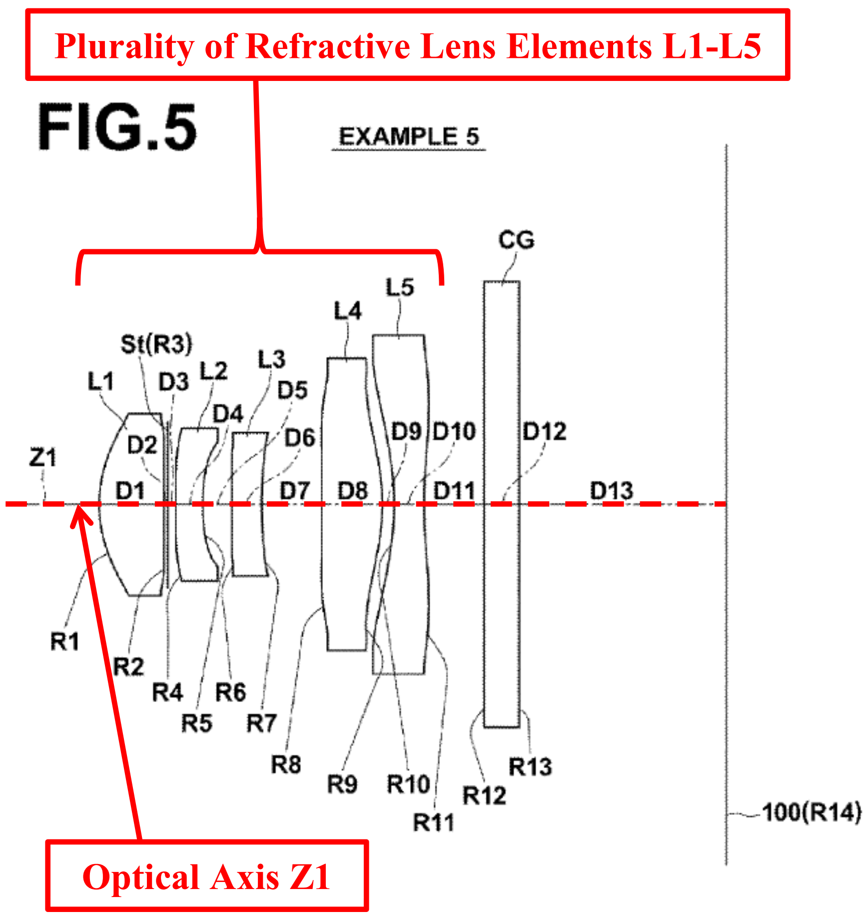
Id., 22:10-35. Table 9 includes column 'Di' corresponding to the on-axis thickness of and spacing between each lens element; column 'ndj' providing the refractive index of each lens element L1-L5 and the optional member CG; and column 'vdj' providing the Abbe number of each lens element L1-L5 and the optional member CG. *See, e.g., id.*, 14:31-53. Also included in Table 9 is "the focal length f of the whole system (mm)" designated as "f=5.956," "the back focal length Bf (mm)" designated as "BF=2.438," and "the total lens length TL (mm)" designated as 5.171 mm, which is the total track length of the lens system without the cover glass element. *Id.*, 14:47-50, 21:10-15.

Ogino provides the back focal length Bf and the total lens length TL as if the optional optical member CG was removed and only air existed between the fifth lens element L5 and the image plane. APPL-1003, ¶45. The total track length <u>with</u> the optical member CG can be calculated, though, by summing the widths D1 to D13 and is 5.273 mm. *Id.* As shown below, Example 5 with the cover glass member anticipates claims 1, 4, 9-15, 17, 20, and 25-29 of the '897 Patent. A claim chart corresponding to the analysis below is contained in Dr. Sasián's expert declaration. *See* APPL-1003, pp.27-55.

2. Claim 1

[1.0] A lens assembly, comprising a plurality of lens elements arranged along an optical axis and spaced apart by respective spaces,

Ogino discloses this limitation because it teaches "an imaging lens substantially consisting of, in order from an object side, five lenses." APPL-1005, 2:1-3. A POSITA would have considered an imaging lens consisting of five lenses to be a "lens assembly." APPL-1003, p.27. Ogino's Example 5 lens assembly from Fig. 5 is reproduced below:



APPL-1005, Fig.5 (annotated). As can be observed from Example 5, lens elements L1-L5 are spaced apart "**<u>on an optical axis Z1</u>**." *Id.*, 5:13-15.

Thus, Ogino's Example 5 teaches this limitation. APPL-1003, p.28.

[1.1] wherein the lens assembly has an effective focal length (EFL),

As discussed above, the term "effective focal length (EFL)" is construed to mean "*the focal length of a lens assembly*." In that regard, Ogino states "f is a focal length of a whole system" (APPL-1005, 3:16) and the focal length f of the Example 5 lens assembly is represented in Table 9 as f = 5.956 mm (*see id.*, 14:47-53 (units in mm)):

Effective Focal Length (EFL)

TABLE 9

EXAMPLE 5

f = 5.956, Bf = 2.438, TL = 5.171

Si	Ri	Di	ndj	vdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	0.506	1.63351	23.63
*9	−1.70702	0.100		
*10	−2.17464	0.253	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

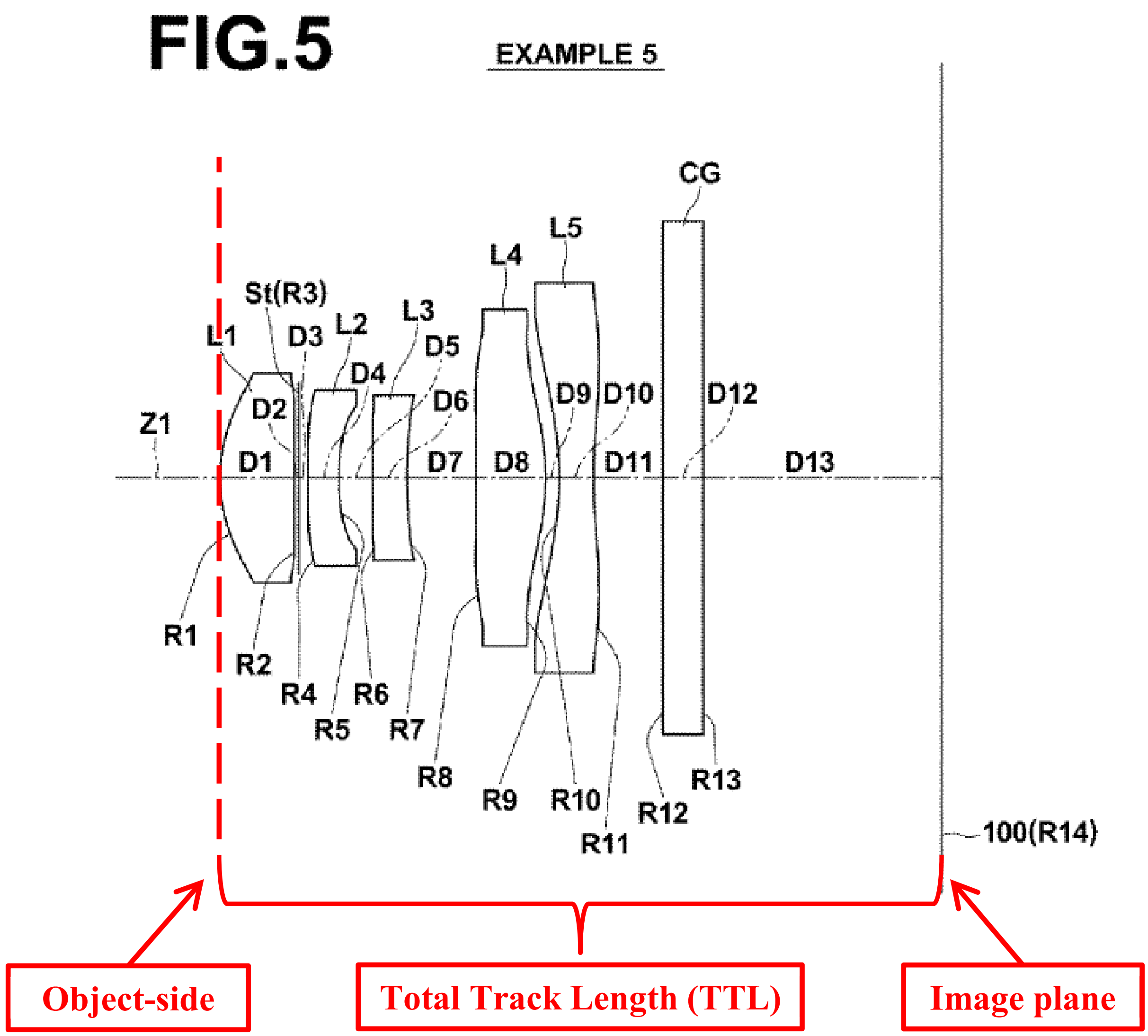
*ASPHERIC SURFACE

APPL-1003, p.29; APPL-1005, Table 9 (annotated).

Thus, Ogino's Example 5 lens assembly with an EFL of 5.956 mm teaches this limitation. APPL-1003, p.29.

[1.2] a total track length (TTL) of 6.5 millimeters or less

Ogino discloses this limitation because Example 5 has a total track length (TTL) including the cover glass of 5.273 mm which is less than 6.5 mm. *Id.* As discussed above, the term "total track length (TTL)"is construed to mean "*the length of the optical axis spacing between the object-side surface of the first lens element and one of: an electronic sensor, a film sensor, and an image plane corresponding to either the electronic sensor or a film sensor*." As shown below in Fig. 5, a POSITA would have identified the total track length of Example 5 to be the distance between the object-side surface of the first lens L1 and the image plane 100 (R14). APPL-1003, p.30.



APPL-1003, p.30; APPL-1005, Fig. 5 (annotated).

Using the lens data for Example 5 from Table 9, the TTL with the cover glass element can be calculated by summing the widths above labeled D1 to D13:

TABLE 9

EXAMPLE 5
f = 5.956, Bf = 2.438, TL = 5.171

Si	Ri	Di	ndj	vdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	0.506	1.63351	23.63
*9	−1.70702	0.100		
*10	−2.17464	0.253	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

*ASPHERIC SURFACE

Widths of L1 to L13

TTL = (sum of D1 to D13)

APPL-1003, pp.30-31; APPL-1005, Table 9 (annotated). The sum of the distances D1 to D13 is thus 5.273 mm. APPL-1003, p.31; *id.*, Appendix, Fig. 1A.

Thus, Ogino's Example 5 with a TTL of 5.273 mm this limitation. APPL-1003, pp.31-32.

[1.3] and a ratio TTL/EFL<1.0,

Ogino discloses this limitation because, as established above in [1.1] and [1.2], the total track length of Example 5 is less than its effective focal length. *Id.*, p.32. Specifically, as established in [1.1], the EFL of Example 5 is 5.956 mm. *See* APPL-1005, Table 9. As established in [1.2], the TTL of Example 5 with the cover glass element is 5.273 mm. *See* APPL-1003, p.32; APPL-1005, Table 9 (summing D1-D13). Accordingly, the ratio of TTL/EFL for Example 5 is:

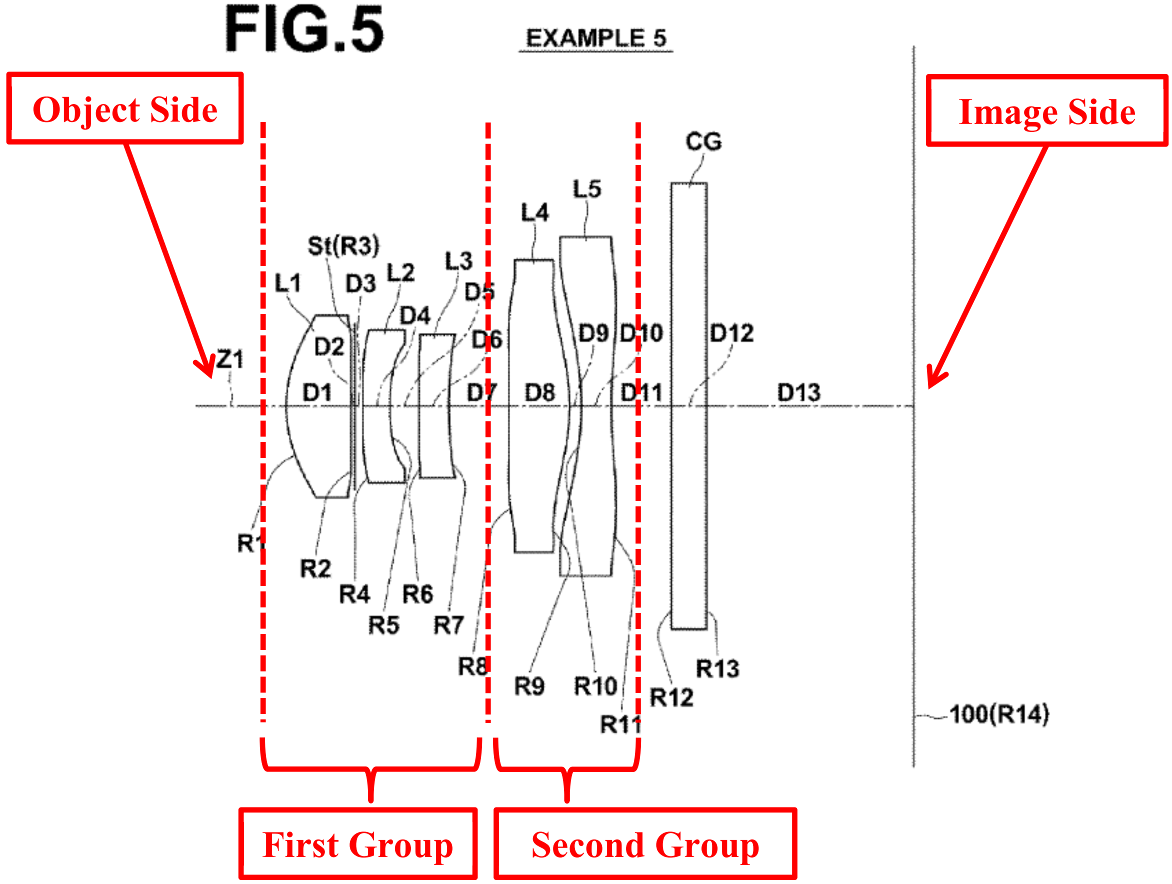
$$\frac{5.273\,mm}{5.956\,mm} = 0.8853 < 1.0$$

See APPL-1003, p.32. Thus, Ogino's Example 5 with a TTL/EFL ratio of 0.8853 teaches this limitation. *Id.*, p.32.

[1.4] wherein the plurality of lens elements includes, in order from an object side to an image side, a first group comprising lens elements L_{1_1}, L_{1_2} and L_{1_3} with respective focal lengths f_{1_1}, f_{1_2} and f_{1_3} and a second group comprising lens elements L_{2_1} and L_{2_2},

Ogino discloses this limitation because the Example 5 lens assembly includes a first lens group with three lens elements L1-L3 in order (i.e., L_{1_1}, L_{1_2}, and L_{1_3}) and a second lens group with two lens elements L4-L5 in order (i.e., L_{2_1} and L_{2_2}) as shown in Fig. 5:

FIG.5



APPL-1003, p.33; APPL-1005, Fig. 5 (annotated).

Each lens element L_{1_1}, L_{1_2}, and L_{1_3} in Example 5 has a respective focal length that can be calculated using the focal length of the whole system and the data provided in Table 13 for Example 5, which shows f/f1=2.88, f/f2=-1.88, and f/f3=-0.86:

TABLE 13

VALUES IN CONDITIONAL EXPRESSIONS						
EXPRESSION NUMBER	CONDITIONAL EXPRESSIONS	EXAMPLE 1	EXAMPLE 2	EXAMPLE 3	EXAMPLE 4	EXAMPLE 5
(1)	f/f1	1.8	1.7	1.68	2.49	2.88
(2)	f/f2	−1.22	−0.98	−1.1	−1.83	−1.88
(3)	f/f12	0.91	0.98	0.84	1.17	1.52
(4)	f/f345	−0.2	−0.37	−0.08	−0.42	−1.04
(5)	f1/f3	0.15	0.05	0.2	−0.03	−0.3
(6)	(R3f − R3r)/(R3f + R3r)	−0.18	−0.03	−0.48	0.73	0.98
(7)	f/f5	−0.55	−1.1	−1.88	−1.51	−2.43
(8)	f· tanω/R5r	1.7	0.86	1.5	1.66	1.44
(9)	f/f3	0.27	0.09	0.34	−0.06	−0.86
(10)	D7/f	0.12	0.12	0.14	0.11	0.08

f/f1

f/f2

f/f3

APPL-1003, pp.33-34; APPL-1005, Table 13 (annotated).

Using this information, the focal lengths for L_{1_1}, L_{1_2}, and L_{1_3} can be calculated as follows:

$$2.88 = \frac{f}{f1} \rightarrow f1 = \frac{f}{2.88} = \frac{5.956\,mm}{2.88} = \mathbf{2.068\,mm}$$

$$-1.88 = \frac{f}{f2} \rightarrow f2 = \frac{f}{-1.88} = \frac{5.956\,mm}{-1.88} = \mathbf{-3.168\,mm}$$

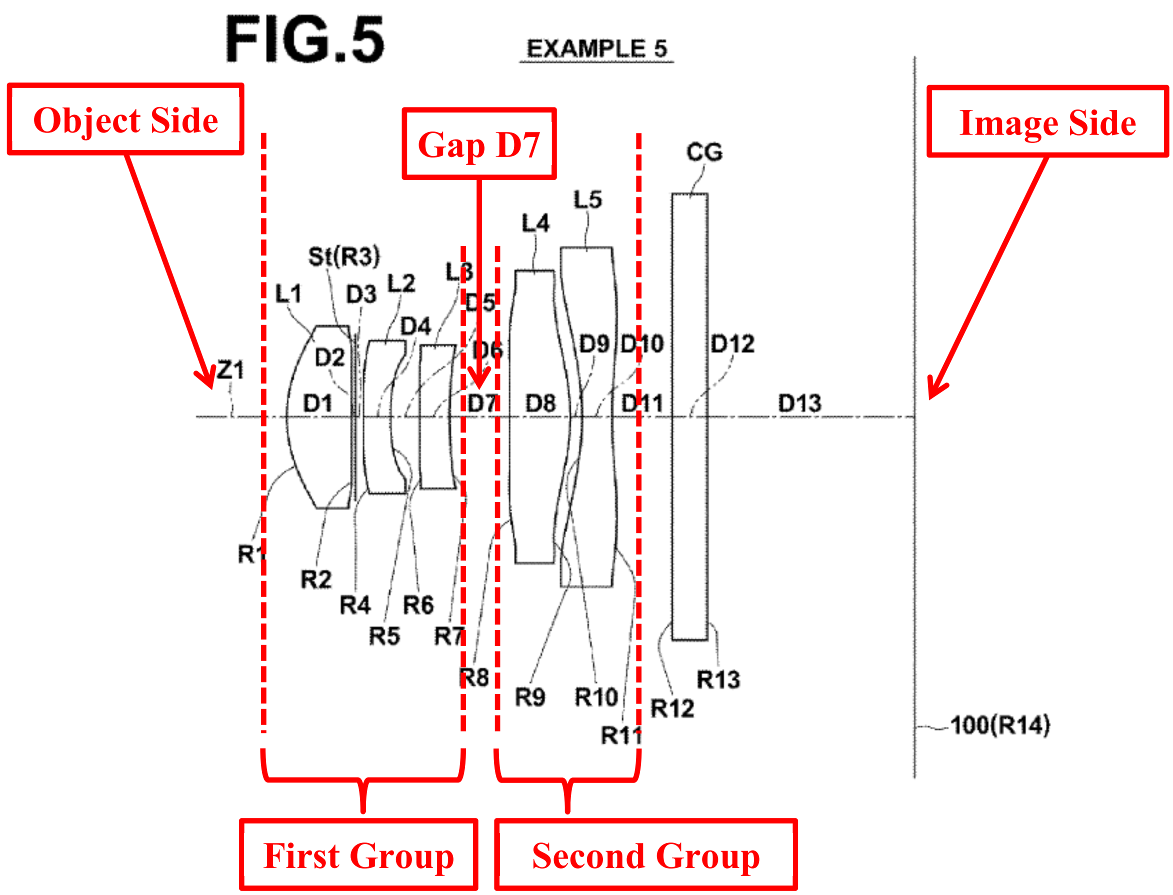
$$-0.86 = \frac{f}{f3} \rightarrow f3 = \frac{f}{-0.86} = \frac{5.956\,mm}{-0.86} = \mathbf{-6.926\,mm}$$

APPL-1003, p.34.

Thus, Ogino's Example 5 that includes lenses L1-L3, each with respective focal lengths, in a first group and lenses L4-L5 in a second group teaches this limitation. *Id.*

[1.5] wherein the first and second groups of lens elements are separated by a gap that is larger than twice any other gap between lens elements,

Ogino discloses this limitation because the Example 5 lens assembly includes a gap D7 between the first group (L1-L3) and the second group (L4-L5) that is twice larger than any other gap between lens elements. APPL-1003, pp.34-35. As established in [1.3], the Example 5 lens assembly has first and second groups of lenses separated by a gap labeled D7:



APPL-1003, p.35; APPL-1005, Fig. 5 (annotated).

The gap between the other lens elements are identified as D2+D3 (between L1 and L2), D5 (between L2 and L3), and D9 (between L4 and L5). The widths of

each gap D2+D3 (with the aperture stop in the middle, which is not a lens element), D5, D7, and D9 are provided in Table 9:

TABLE 9

EXAMPLE 5
f = 5.956, Bf = 2.438, TL = 5.171

Si	Ri	Di	ndj	vdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	0.506	1.63351	23.63
*9	1.70702	0.100		
*10	−2.17464	0.253	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

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D2+D3

D5

D7

D9

APPL-1003, p.36; APPL-1005, Table 9 (annotated). Based on this data, the following calculations show that D7 is twice larger than the other gaps between lens elements:

$$D7 > 2 \times (D2 + D3) \rightarrow \mathbf{0.506} > \mathbf{0.198}\ (2 \times 0.099)$$

$$D7 > 2 \times D5 \rightarrow \mathbf{0.506} > \mathbf{0.486}\ (2 \times 0.243)$$

$$D7 > 2 \times D9 \rightarrow \mathbf{0.506} > \mathbf{0.200}\ (2 \times 0.100)$$

APPL-1003, p.36.

Thus, since Ogino's Example 5 has a gap D7 between the first and second lens groups that is twice larger than gaps D2+D3, D5, and D9, Example 5 teaches this limitation. *Id.*, pp.36-37.

[1.6] wherein lens element L_{1_1} has positive refractive power and lens element L_{1_2} has negative refractive power,

Ogino discloses this limitation because the optical data for the Example 5 lens assembly shows that the L1 lens element (i.e., L_{1_1}) has positive refractive power and the L2 lens element (i.e., L_{1_2}) has negative refractive power. *Id.*, p.37.

A POSITA would have recognized that the refractive power of a lens is equal to the inverse of the focal length of the lens: "[t]he practical unit of power is a *dioptre*; **<u>it is the reciprocal of the focal length</u>**, when the focal length is expressed in meters." APPL-1010, p.159. As established above in [1.3], the L1 lens has a positive focal length of 2.068 mm thereby indicating a positive refractive power and the L2 lens has a negative focal length of -3.168 mm thereby indicating a negative refractive power. *See* APPL-1003, p.37.

Thus, Ogino's Example 5 with a positive L1 lens and a negative L2 lens teaches this limitation. *Id.*

[1.7] and wherein lens elements L_{2_1} and L_{2_2} have opposite refractive powers.

Ogino discloses this limitation because the Example 5 lens assembly includes lens L4 (i.e., L_{2_1}) and lens L5 (i.e., L_{2_2}) having opposite refractive powers. *Id.* First, while not given in Ogino, the focal length f4 of the L4 lens can be calculated by inputting the optical data for the lens into the commonly known "lens maker's equation" for lenses separated by a gap, as stated in Born:

$$f = -\frac{n\, r_1\, r_2}{(n-1)[n(r_1 - r_2) - (n-1)t]}$$

where f is the focal length of the lens, n is the index of refraction, r_1 and r_2 are the curvature of the lens's two surfaces, and t is the axial thickness of the lens. *See* APPL-1010, p.161-62 *See* APPL-1003, pp.37-38.

The data in Table 9 corresponding to L4 to be used in the above equation is indicated below:

TABLE 9

EXAMPLE 5

f = 5.956, Bf = 2.438, TL = 5.171

Si	Ri	Di	ndj	νdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	0.506	1.63351	23.63
*9	−1.70702	0.100		
*10	−2.17464	0.253	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

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r_1

r_2

Axial Thickness of Lens L4 (*t*)

Index of Refraction of Lens L4 (*n*)

APPL-1003, p.39; APPL-1005, Table 9 (annotated).

Accordingly, for the L4 lens, the curvature of the object-side surface (r_1) is -99.83715 mm, the curvature of the image-side surface (r_2) is -1.70702 mm, the index of refraction (n) is 1.63351, and the axial thickness (t) is 0.506 mm. Using these values in the above equation for f_4 yields:

$$-\frac{1.63351 \times -99.83715 \times -1.70702}{(1.63351 - 1)[1.63351(-99.83715 - -1.70702) - (1.63351 - 1) \times 0.506]} =$$

$$-\frac{278.389}{-101.753} = \mathbf{2.7359\ mm}$$

Thus, the focal length of the L4 lens (i.e., L_{2_1}) is 2.7359 mm. *Id.*, pp.39-40.

Second, the focal length of the L5 lens (i.e., L_{2_2}) can be calculated using the value f/f5=-2.43 from Table 13:

TABLE 13

VALUES IN CONDITIONAL EXPRESSIONS						
EXPRESSION NUMBER	CONDITIONAL EXPRESSIONS	EXAMPLE 1	EXAMPLE 2	EXAMPLE 3	EXAMPLE 4	EXAMPLE 5
(1)	f/f1	1.8	1.7	1.68	2.49	2.88
(2)	f/f2	−1.22	−0.98	−1.1	−1.83	−1.88
(3)	f/f12	0.91	0.98	0.84	1.17	1.52
(4)	f/f345	−0.2	−0.37	−0.08	−0.42	−1.04
(5)	f1/f3	0.15	0.05	0.2	−0.03	−0.3
(6)	(R3f − R3r)/(R3f + R3r)	−0.18	−0.03	−0.48	0.73	0.98
(7)	f/f5	−0.55	−1.1	−1.88	−1.51	$\boxed{-2.43}$
(8)	f·tanω/R5r	1.7	0.86	1.5	1.66	1.44
(9)	f/f3	0.27	0.09	0.34	−0.06	−0.86
(10)	D7/f	0.12	0.12	0.14	0.11	0.08

f/f5

APPL-1003, p.40; APPL-1005, Table 13 (annotated). The focal length f5 of the L5 lens can be calculated using the same method described in [1.4]:

$$-2.43 = \frac{f}{f5} \rightarrow f5 = \frac{f}{-2.43} = \frac{5.956\ mm}{-2.43} = \mathbf{-2.451\ mm}$$

Thus, the L4 lens has a focal length f_4 = 2.7359 mm and the L5 lens has a focal length f_5 = -2.451 mm. APPL-1003, p.40. Because L4 is positive and L5 is negative, they have opposite refractive powers. *Id.*

Thus, Ogino's Example 5 with lenses L4 and L5 in the second group having opposite powers teaches this limitation. *Id.*

3. Claim 4

[4.0] The lens assembly of claim 1, wherein f_{1_1}<TTL/2.

Ogino discloses this limitation because the L1 lens (i.e., L_{1_1}) in the Example 5 lens assembly has a focal length (f_{1_1}) that is less than half of the TTL of the lens assembly including the cover glass. *Id.*, p.41. First, as established in [1.4], the L1 lens has a focal length f_{1_1} of 2.068 mm. Second, as established in [1.2], the TTL of Example 5 with the cover glass element is 5.273 mm. Example 5 thus meets the claimed ratio f_{1_1}<TTL/2 as shown below:

$$2.068\,mm < \frac{5.273\,mm}{2} \rightarrow \mathbf{2.068\,mm < 2.637\,mm}$$

Id. Thus, Ogino's Example 5 teaches this limitation. *Id.*

4. Claim 9

[9.0] The lens assembly of claim 1, wherein 1.2×|f_{1_3}|>1.5×f_{1_1}.

Ogino discloses this limitation because the L1 (i.e., L_{1_1}) and L3 (i.e., L_{1_3}) lenses in the Example 5 lens assembly meet the claimed expression as shown below. *Id.* As established in [1.4], the focal length of the L1 lens (i.e., f_{1_1}) is 2.068 mm and the focal length of the L3 lens (i.e., f_{1_3}) is -6.926 mm. *Id.* Applying these to the claimed expression 1.2 x |f_{1_3}| > 1.5 x f_{1_1} yields:

$$1.2 \times |\text{-}6.926\,mm| > 1.5 \times 2.068\,mm \rightarrow \mathbf{8.3112\,mm > 3.102\,mm}$$

Id. Thus, Ogino's Example 5 teaches this limitation. *Id.*

5. Claim 10

[10.0] The lens assembly of claim 1, wherein 1.2×|f_{1_3}|>|f_{1_2}|>1.5×f_{1_1}.

Ogino discloses this limitation because the L1 (i.e., L_{1_1}), L2 (i.e., L_{1_2}), and L3 (i.e., L_{1_3}) lenses in the Example 5 lens assembly meet the claimed expression as shown below. *Id.*, p.42. As established in [1.4], the focal length of the L1 lens (i.e., f_{1_1}) is 2.068 mm, the focal length of the L2 lens (i.e., f_{1_2}) is -3.168 mm, and the focal length of the L3 lens (i.e., f_{1_3}) is -6.926 mm. Applying these values to the claimed expression $1.2\times|f_{1\_3}|>|f_{1\_2}|>1.5\times f_{1\_1}$ yields:

$$1.2 \times |\text{-}6.926\,mm| > |\text{-}3.168\,mm| > 1.5 \times 2.068\,mm \rightarrow$$

$$\mathbf{8.3112\,mm > \;\; 3.168\,mm \; > 3.102\,mm}$$

Id. Thus, Ogino's Example 5 teaches this limitation. *Id.*

6. Claim 11

[11.0] The lens assembly of claim 1, wherein a combined power of lens elements L_{1_2} and L_{1_3} is negative.

Ogino discloses this limitation because the L2 (i.e., L_{1_2}) and L3 (i.e., L_{1_3}) lenses in the Example 5 lens assembly have a combined negative power. *Id.* First, as established in [1.4], the focal length of the L2 lens (i.e., f_{1_2}) is -3.168 mm and the focal length of the L3 lens (i.e., f_{1_3}) is -6.926 mm. *Id.* Second, as established above in [1.6] the refractive power of a lens in the inverse of its focal length. *See id.*; APPL-1010, p.159. Therefore, the optical power of the second lens L2 is 1/f2

(the reciprocal of the focal length f2) and the optical power of the third lens L3 is 1/f3 (the reciprocal of the focal length f3).

Third, Walker (APPL-1016) provides the equation for finding the approximate combined optical power ($\phi_{combined}$) of two lenses:

$$\phi_{combined} = \phi_1 + \phi_2 - (d\ \phi_1\ \phi_2)$$

where ϕ_1 and ϕ_2 are individual lens powers and d is lens separation.

APPL-1016, p.65. The equation above modified for focal length rather than optical power is thus:

$$\phi_{combined} = \left(\frac{1}{f2} + \frac{1}{f3}\right) - \left(d * \frac{1}{f2} * \frac{1}{f3}\right)$$

APPL-1003, p.43. Substituting the focal lengths for L2 (-3.168 mm) and L3 (-6.926 mm) and the distance between L2 and L3 as provided in Table 9 (0.243 mm) yields:

$$\left(\frac{1}{-3.168} + \frac{1}{-6.926}\right) - \left(0.243 \times \frac{1}{-3.168} \times \frac{1}{-6.926}\right) = -0.471\ mm^{-1}$$

Id. p.44. The combined power of the L2 and L3 lenses is therefore negative. *Id.* Further, a POSITA would have known that the optical power of the combination of two lenses each with negative optical power is also negative optical power. *Id.*

Thus, Ogino's Example 5 teaches this limitation. *Id.*, pp.44-45.

7. Claim 12

[12.0] The lens assembly of claim 1, wherein L_{1_3} has negative refractive power.

Ogino discloses this limitation because the L3 lens (i.e., L_{1_3}) in Example 5 has negative refractive power. *Id.*, p.45. First, as established in [1.4], the L3 lens has a focal length of -6.926mm. Second, as established in [1.6] the refractive power of a lens is the inverse of its focal length. *Id.*; APPL-1010, p.159. The refractive power of the L3 lens is therefore negative. APPL-1003, p.44. Thus, Ogino's Example 5 teaches this limitation. *Id.*

8. Claim 13

[13.0] The lens assembly of claim 1, wherein the gap between lens elements L_{2_1} and L_{2_2} is smaller than $1.5 \times d_{2\_2}$ where d_{2_2} is a thickness of lens element L_{2_2} along the optical axis.

Ogino discloses this limitation because the L4 lens (i.e., L_{2_1}) and the L5 lens (i.e., L_{2_2}) in Example 5 are separated by a gap (*d*) smaller than $1.5 \times d_{2\_2}$. *Id.* First, the values for the gap (*d*) between L4 and L5 and the thickness of L5 (i.e., d_{2_2}) are provided in Table 9:

TABLE 9

EXAMPLE 5
f = 5.956, Bf = 2.438, TL = 5.171

Si	Ri	Di	ndj	νdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	$\boxed{0.506}$	1.63351	23.63
*9	−1.70702	$\boxed{0.100}$		
*10	−2.17464	$\boxed{0.253}$	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

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L4

L5

Gap *d* between Lenses L4 and L5

APPL-1003, p.46; APPL-1005, Table 9 (annotated). Applying these values to the claimed expression $d<1.5\times d_{2\_2}$ yields:

$$d < 1.5 \times d_{2\_2} \rightarrow 0.100mm < 1.5 \times 0.253mm \rightarrow \mathbf{0.100mm < 0.3795mm}$$

Id., p.46.

Thus, Ogino's Example 5 teaches this limitation. *Id.*

9. Claim 14

[14.0] The lens assembly of claim 1, wherein lens elements L_{2_1} and L_{2_2} are separated by a gap smaller than TTL/20.

Ogino discloses this limitation because the L4 lens (i.e., L_{2_1}) and the L5 lens (i.e., L_{2_2}) in Example 5 are separated by a gap (*d*) smaller than TTL/20. *Id.*, p.47. First, the value for gap (*d*) between L4 and L5 is provided in Table 9:

TABLE 9

EXAMPLE 5
f = 5.956, Bf = 2.438, TL = 5.171

Si	Ri	Di	ndj	vdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	0.506	1.63351	23.63
*9	−1.70702	0.100		
*10	−2.17464	0.253	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

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L4

L5

Gap *d* between Lenses L4 and L5

Id.; APPL-1005, Table 9 (annotated).

Second, as discussed above in [1.2], Example 5 with the cover glass element has a TTL of 5.273mm. APPL-1003, p.47. Applying these values to the claimed expression yields:

$$d < \frac{TTL}{20} \rightarrow 0.100\,mm < \frac{5.273\,mm}{20} \rightarrow \mathbf{0.100\,mm < 0.26365\,mm}$$

Id., p.48. Thus, Ogino's Example 5 teaches this limitation. *Id.*

10. Claim 15

[15.0] The lens assembly of claim 1, wherein L_{2_1} and L_{2_2} are made of different lens materials having different Abbe numbers, such that one lens element has Abbe number that is smaller than 30 and the other lens element has an Abbe number that is larger than 50.

Ogino discloses this limitation because the L4 lens (i.e., L_{2_1}) and the L5 lens (L_{2_2}) in Example 5 have respective Abbe numbers greater than 50 and less than 30. *Id.* As indicated in the column labeled "vdj" in Table 9 (representing Example 5), the Abbe number of L4 is 23.63 (i.e., less than 30) and the Abbe number of L5 is 54.87 (i.e., larger than 50):

Abbe No. of L4 (L_{2_1})

TABLE 9

EXAMPLE 5
f = 5.956, Bf = 2.438, TL = 5.171

Si	Ri	Di	ndj	vdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	0.506	1.63351	23.63
*9	−1.70702	0.100		
*10	−2.17464	0.253	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

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Index of Refraction for L4 and L5

Abbe No. of L5 (L_{2_2})

APPL-1003, pp.48-49; APPL-1005, Table 9 (annotated).

The L4 and L5 lenses are different materials because, in addition to having different Abbe numbers as discussed above, L4 has an index of refraction (ndj) of 1.63351 and the L5 has an index of refraction of 1.54488. *See* APPL-1018, p.27; APPL-1003, p.49. Thus, Ogino's Example 5 teaches this limitation. *Id.*, p.50.

11. Claim 17

[17.0] A lens assembly, comprising: a plurality of lens elements arranged along an optical axis and spaced apart by respective spaces,

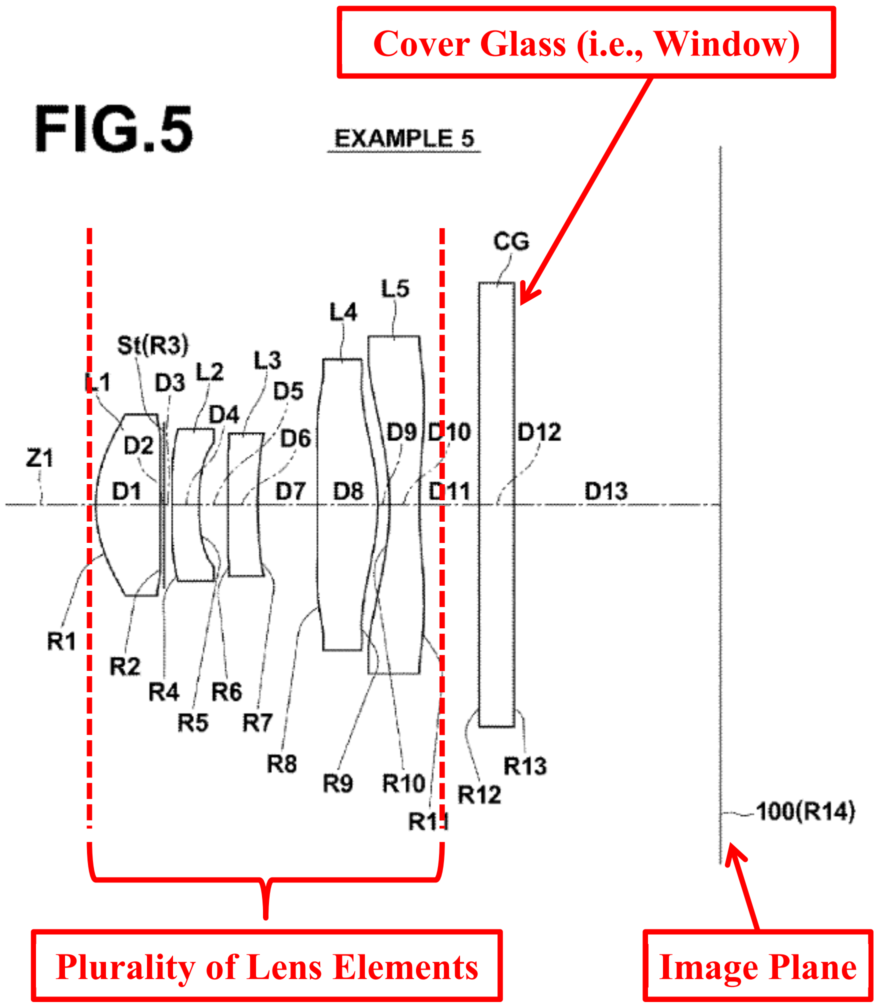
This limitation is the same as [1.0] and is disclosed for the same reasons discussed above. *Id.*

[17.1] wherein the lens assembly has an effective focal length (EFL),

This limitation is the same as [1.1] and is disclosed for the same reasons discussed above. *Id.*

[17.2] wherein a lens system that includes the lens assembly plus a window positioned between the plurality of lens elements and an image plane

Ogino discloses this limitation because the Example 5 lens assembly includes a cover glass (i.e., window) between the L5 lens element and the image plane as shown in Fig. 5 below:



APPL-1003, p.51; APPL-1005, Fig. 5 (annotated). Ogino defines the CG element as "a flat-plate-shaped optical member, such as a coverglass for protecting an imaging surface and an infrared ray cut filter …." APPL-1005, 5:58-60.

A POSITA would have understood that the cover glass is a window since the cover glass has parallel surfaces, transmits light, and protects the lens assembly. APPL-1003, p.51. Thus, Ogino's Example 5 teaches this limitation. *Id.*

[17.3] has a total track length (TTL) of 6.5 millimeters or less,

This limitation is the same as [1.2] and is disclosed for the same reasons discussed above. *Id.*

[17.4] wherein a ratio TTL/EFL<1.0,

This limitation is the same as [1.3] and is disclosed for the same reasons discussed above. *Id.*, p.52

[17.5] wherein the plurality of lens elements includes, in order from an object side to an image side, a first group comprising lens elements L_{1_1}, L_{1_2} and L_{1_3} with respective focal lengths f_{1_2} and f_{1_3}, and a second group comprising lens elements L_{2_1} and L_{2_2},

This limitation is the same as [1.4] and is disclosed for the same reasons discussed above. *Id.*

[17.6] wherein lens element L_{1_1} has positive refractive power and lens element L_{1_2} has negative refractive power,

This limitation is the same as [1.6] and is disclosed for the same reasons discussed above. *Id.*

[17.7] wherein $1.2\times|f_{1\_3}|>|f_{1\_2}|>1.5\times f_{1\_1}$,

This limitation is the same as [10.0] and is disclosed for the same reasons discussed above. *Id.*

[17.8] and wherein lens elements L_{2_1} and L_{2_2} have opposite refractive powers.,

This limitation is the same as [1.7] and is disclosed for the same reasons discussed above. *Id.*

12. Claim 20

[20.0] The lens assembly of claim 17, wherein f_{1_1}<TTL/2.

This limitation is the same as [4.0] and is disclosed for the same reasons discussed above. *Id.*

13. Claim 25

[25.0] The lens assembly of claim 17, wherein a combined power of lens elements L_{1_2} and L_{1_3} is negative.

This limitation is the same as [11.0] and is disclosed for the same reasons discussed above. *Id.*, p.53.

14. Claim 26

[26.0] The lens assembly of claim 17, wherein L_{1_3} has negative refractive power.

This limitation is the same as [12.0] and is disclosed for the same reasons discussed above. *Id.*

15. Claim 27

[27.0] The lens assembly of claim 17, wherein a gap between lens elements L_{2_1} and L_{2_2} is smaller than $1.5\times d_5$, where d_5 is a thickness of lens element L_{2_2} along the optical axis.

This limitation is the same as [13.0] and is disclosed for the same reasons discussed above. *Id.*

16. Claim 28

[28.0] The lens assembly of claim 17, wherein lens elements L_{2_1} and L_{2_2}, are separated by a gap smaller than TTL/20.

This limitation is the same as [14.0] and is disclosed for the same reasons discussed above. *Id.*

17. Claim 29

[29.0] The lens assembly of claim 17, wherein L_{2_1}, and L_{2_2} are made of different lens materials having different Abbe numbers, such that one lens element has an Abbe number that is smaller than 30 and the other lens element has an Abbe number that is larger than 50.

This limitation is the same as [15.0] and is disclosed for the same reasons discussed above. *Id.*, p.54.

D. Ground 2: Claims 2, 5, 6, 18, and 21-23 are obvious under 35 U.S.C. § 103 over Ogino in view of Bareau.

1. Summary of Bareau

Bareau refers to "The optics of miniature digital camera modules" by Jane Bareau and Peter P. Clark (APPL-1012). Bareau generally discusses how "[d]esigning lenses for cell phone cameras is different from designing for traditional imaging systems." APPL-1012, p.1. Bareau offers "typical lens specifications" for use in cellular telephones, which include an f-number of 2.8 or less so that enough light will be supplied to ¼" and smaller sensor formats. *Id.*, pp.3-4. Bareau also indicates a preference for a TTL of about 5.0 mm due to a desire to make the cell phone thin as well as maintaining relative illumination at the edge of the field of greater than 50 percent. *Id.*, pp.3,7. A POSITA would have understood these to be general specifications with some modifications allowed

depending on the specific implementation, sensor, and desired purpose. *See* APPL-1024 (Wang), 1:30-53.

Bareau also generally describes the understanding of a POSITA that designing photographic lenses with a low f-number has been and continues to be an important trend in lens design. *See, e.g.*, *id.*, pp.3-4. Bareau therefore serves as evidence that a POSITA would have considered two main driving factors for cell phone lens specifications including a small total track length (TTL) to make the overall cell phone thin and a low f-number to allow enough light to reach the sensor. *See* APPL-1003, ¶49; APPL-1012, pp.3-4.

Thus, a POSITA designing lens assemblies for use in a cell phone would have been informed by Bareau to design or modify a lens system that fit within the specifications including maintaining a short track length, an f-number of 2.8 or lower for ¼" and smaller sensor formats, and relative illumination greater than 50 percent. APPL-1003, ¶59.

2. Reasons to combine Ogino and Bareau

A POSITA would have found it obvious to modify Ogino's Example 5 lens assembly in view of Bareau's specifications for cell phone camera lenses with an F#=2.8 or less for ¼" and smaller image sensors. *Id.*, ¶51; *see also* APPL-1024, 1:23-53. Such a combination would have been simple been applying Bareau's specification for a brighter lens system for smaller image sensors, according to

known lens design and modification methods (as taught in APPL-1017, p.172), to yield a predictable result of Ogino's Example 5 lens assembly likewise supporting an f-number of 2.8 or lower for a small sensor format. *Id.*; *See* APPL-1012, pp.3-4.

Bareau was published in 2006. By 2013 (the priority date of the '897 Patent), cell phones having cameras with F#=2.8 for ¼" and smaller sensor formats were common and it was at least expected that cell phone camera lenses would satisfy similar specifications. APPL-1003, ¶52; *see* APPL-1012, p.3. A POSITA's desire to achieve lens designs with lower f-numbers was also well known and driven by a recognized need for "faster" lenses. *See* APPL-1013, p.104 ("The tremendous efforts of lens designers and manufacturers that have been devoted to the production of lenses of extremely high relative aperture are an indication of **the need that exists for brighter images and 'faster' lenses**."). To have a competitive lens design, a POSITA therefore would have sought to modify existing lens designs to achieve faster f-numbers like 2.8 while still maintaining a short total track length appropriate for thin cell phone designs. APPL-1003, ¶52.

A POSITA thus would have been aware of Bareau's specifications for lens assemblies designed for modern cellular telephones and particularly the importance of supporting a faster f-number for smaller sensor formats. *Id.*, ¶53. Consequently, a POSITA looking to implement a telephoto lens in a cell phone with, for example, a common ¼" sensor format would have been motivated to look to lens designs

like Ogino's that could support a lower, more desirable f-number since Ogino's other embodiments support f-number values down to 2.45 as discussed above. *Id.*; *see also* APPL-1005, Figs. 8-13. Thus, modifying Ogino's Example 5 to have an f-number of 2.8, as taught in Bareau, would have been nothing more than applying Bareau's specification of an F#=2.8 for a ¼" image sensor format according to known lens design methods (as taught in Fischer (APPL-1017)) to allow Example 5 to likewise better support a ¼" sensor format in a thin cell phone. APPL-1003, ¶53.

While Bareau specifies a field of view (FOV) of 60 degrees, this would have been understood to be a design consideration since most cell phones at the time used a single wide lens. *Id.*, ¶54; *see, e.g.*, APPL-1005, Figs. 14, 15. A POSITA designing a cell phone with both wide and telephoto lenses using the same sensor format, (see, e.g., APPL-1014, Fig.16; APPL-1015), though, would have recognized that Bareau's specifications for f-number and short TTL would still be highly relevant to incorporating a telephoto lens like Example 5 since TTL dictates the thickness of the cell phone and the f-number indicates how much light reaches the image sensor regardless of a lens's focal length or FOV. APPL-1003, ¶54; *see also* APPL-1012, pp.3-4. Based on these considerations, a POSITA seeking a telephoto lens with a low f-number would have looked to modify Ogino's Example 5 since Ogino's other examples support lower f-numbers and modifying an

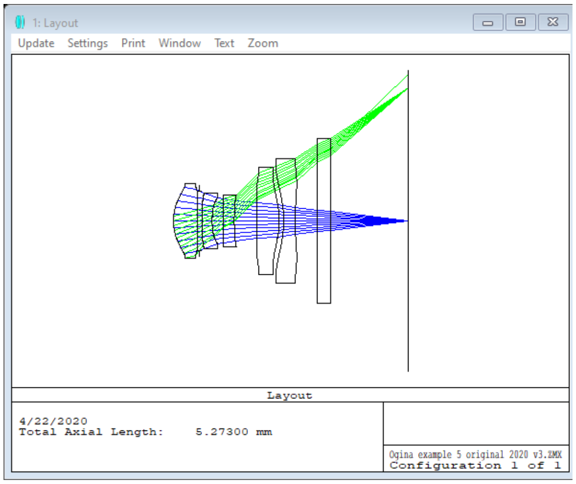
existing lens design takes far less time than starting from scratch, and lens designers often start designs using existing examples in the patent literature. APPL-1003, ¶54.

A POSITA would have understood that one way of modifying Ogino's Example 5 to lower the f-number is to increase the diameter of one or more lens element surfaces, particularly the first lens in Example 5 since this lens serves as the entrance aperture. *Id.*, ¶55. This is due to the relationship between f-number, focal length (EFL), and the diameter of the entrance aperture (i.e. the entrance pupil diameter EPD) which controls the amount of light that enters the assembly:

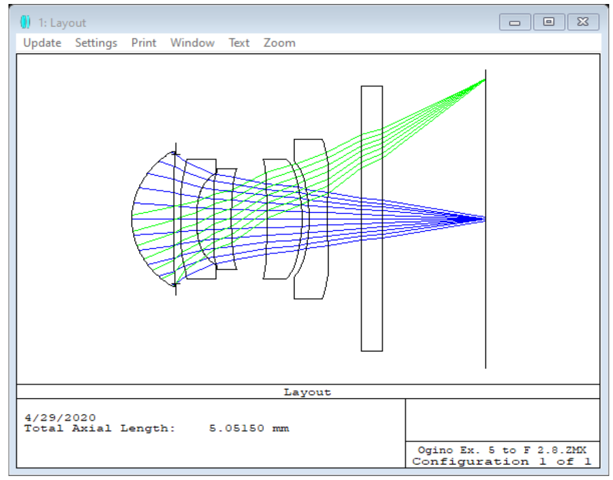
$$f\text{-}number = \frac{EFL}{diameter} = \frac{EFL}{EPD}$$

See APPL-1016, p.59. Given the arrangement of the lenses in Example 5 where the aperture is located behind the first lens L1, a POSITA would have recognized that increasing the diameter of L1's surfaces would thereby also increase the aperture and allow more light to enter the system. APPL-1003, ¶55; *see* APPL-1016, p.60, 67-69 (explaining that a change in the entrance pupil or aperture stop leads to a change in the diameter of the lens).

Modifying Example 5 to achieve Bareau's preferred F#=2.8 by necessarily increasing the diameter of the entrance aperture and using well-known lens design software to find the best solution, a POSITA would have arrived at one possible lens design as shown below:



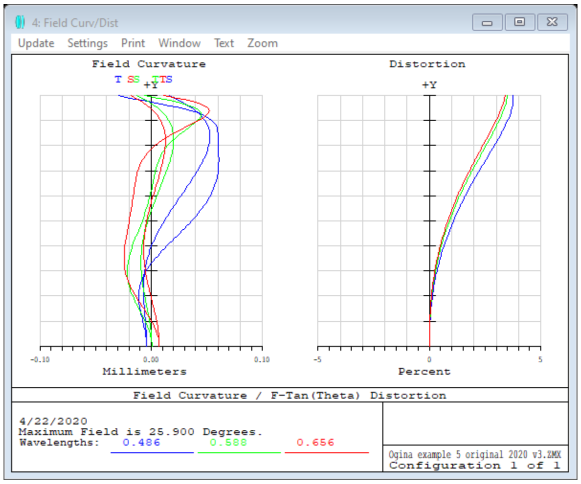
Ogino Example 5 (F#=3.94)



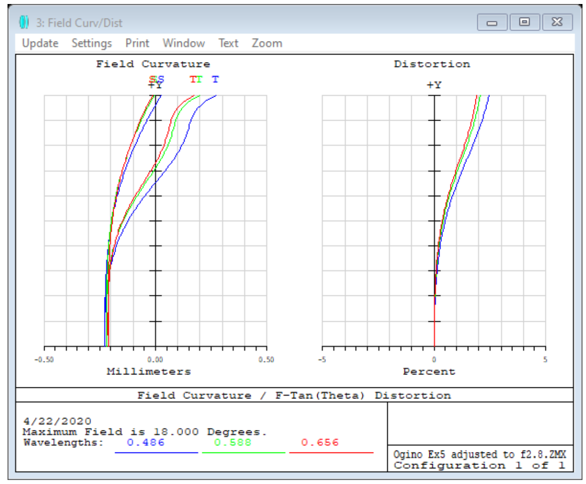
Example 5 modified with F#=2.8

See APPL-1003, ¶56; *id.*, Appendix, Figs. 1A, 2A. In the modified design, EFL=5.648 mm, TTL=5.271 mm, and radii of curvature, spacing, and focal lengths of lens elements L2, L3, L4, and L5 are unchanged. The focal length of L1 is f1=2.0711 mm which is nearly identical to f1 unmodified. *Id.*, ¶56.

Modified Example 5 above supports F#=2.8 while maintaining the same structural design (i.e., focal lengths and spacing) and similar performance characteristics when compared to the original Example 5 design. *Id.*, ¶57. This is shown by comparing the analysis produced by Zemax below:

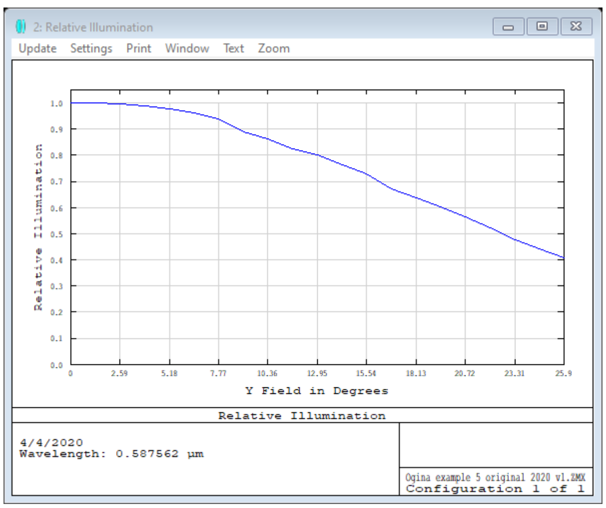


Example 5 (F#=3.94)

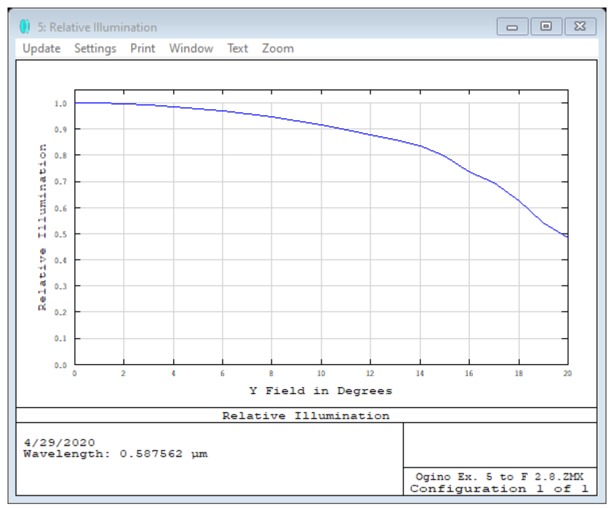


Example 5 modified for F#=2.8

See id.



Relative Illumination of Example 5 (F#=3.94)



Relative Illumination of Example 5 modified for F#=2.8

See id.

As indicated in the prescription data in Fig. 2D below, Example 5 modified for F#=2.8 continues to meet all of the limitations of claim 1 since f1-f5, EFL, TTL, and thicknesses and spacings all still satisfy the respective conditional

expressions discussed above in [1.0]-[1.7]. *Id.*, ¶58. Based on the foregoing reasons, a POSITA thus would have found it obvious, desirable, and predictable to lower the f-number of Example 5 to 2.8 or lower based on Bareau's cell phone lens typical specification of F/2.8 and ¼" sensor, and would have succeeded in doing so as evidenced by the modified design above. *Id.*

To the extent that Patent Owner would argue that modifying Ogino's Example 5 or any other lens deign to lower the f-number would not be obvious, desirable, or possible, such argument would contradict the opinion of its own expert in regard to Patent Owner's own patents. *See* APPL-1023, 119:4-22 (stating that a POSITA would know how to lower an f-number if the design supports it), 121:5-122:13 (stating that a POSITA would know that lower f-number in a cell phone design is better). Thus, based on Patent Owner's own expert and the prior art cited above, a POSITA would have found it obvious and desirable to try to lower the f-number in Ogino's Example 5 embodiment.

The following analysis describes how Ogino's Example 5 modified to support F#=2.8 renders obvious claims 2, 5, 6, 18, and 21-23 of the '897 Patent. A corresponding claim chart is contained in Dr. Sasián's expert declaration. *See* APPL-1003, pp.61-65.

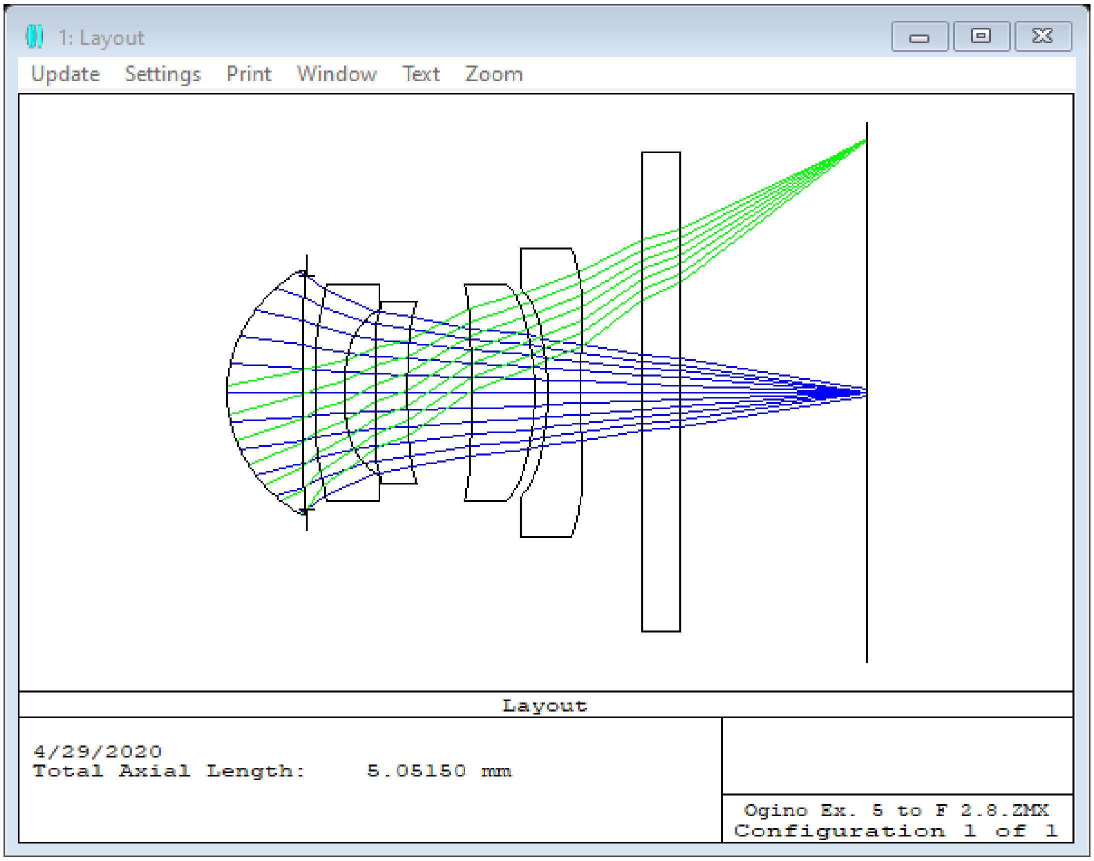
3. Claim 2

[2.0] The lens assembly of claim 1, wherein the TTL is equal or smaller than 6.0 mm and

Ogino discloses this limitation because, as shown in [1.2], the Example 5 lens assembly has a TTL with the cover glass element of 5.273 mm which is less than 6.0 mm. *Id.*, p.62. In the modification above where Example 5 supports F#=2.8, the TTL is maintained to 5.271 mm as compared to the original TTL of 5.273 mm. *Id.* Thus, Ogino's Example 5 modified to support F#=2.8 renders this limitation obvious. *Id.*

[2.1] wherein the lens assembly has a f-number F#<2.9.

Ogino's Example 5 modified to support F#=2.8 renders this limitation obvious. *Id.*, p.61. As shown above, a POSITA would have found it obvious to modify Example 5 based on Bareau's teachings to achieve a telephoto lens with F#=2.8 or less. *Id.* As also shown above, a POSITA would have found this modification to be both predictable and desirable due to Ogino's other disclosed embodiments supporting a lower f-number (*see* APPL-1005, Figs. 8-13), Bareau's teaching of cell phones supporting F#=2.8 or less, and a general desire among POSITAs to design faster lenses (*see* APPL-1013, p.104). APPL-1003, p.61. Example 5 modified for F#=2.8 is provided below with corresponding data provide in Dr. Sasián's Appendix, Fig. 2A:



See id., p.63. Note that the entrance pupil diameter is EPD=2.0171 mm and so the F/#=EFL/EPD=2.8. *Id.*

Thus, Ogino's Example 5 modified based on Bareau's teachings renders this limitation obvious. *Id.*

4. Claim 5

[5.0] The lens assembly of claim 1, wherein the lens assembly has a f-number F#<2.9.

This limitation is the same as [2.1] and is disclosed for the same reasons discussed above. *Id.*

5. Claim 6

[6.0] The lens assembly of claim 5, wherein lens element L_{1_1} has a concave image-side surface.

Ogino discloses this limitation because the L1 lens (i.e., L_{1_1}) in Example 5 "**<u>has a meniscus shape which is convex toward the object side</u>** …." APPL-1005, 13:5-11. A POSITA would have recognized that the description of L1 being meniscus means that the first lens has a convex object-side surface and a concave image-side surface. APPL-1003, p.64. This is because meniscus lenses are commonly known to include one convex side and one concave side. *Id.*; APPL-1010, Fig. 4.15.

Accordingly, a POSITA would have understood that Ogino's description of L1 being meniscus means that the image side is, by definition, concave. APPL-1003, p.64. This is also indicated by the image-side surface in Table 9 having a positive value. *Id.* Example 5 modified for F#=2.8 continues to maintain positive radius of curvature values for both the object- and image-since surfaces of L1. *Id.*

Thus, Ogino's Example 5 lens assembly whether alone or modified to support F#=2.8 renders this limitation obvious. *Id.*

6. Claim 18

[18.0] The lens assembly of claim 17, wherein the TTL is equal or smaller than 6.0 mm

This limitation is the same as [2.0] and is disclosed for the same reasons discussed above. *Id.*, p.66.

[18.1] and wherein the lens assembly has a f-number F#<2.9.

This limitation is the same as [2.1] and is disclosed for the same reasons discussed above. *Id.*

7. Claim 21

[21.0] The lens assembly of claim 17, wherein the lens assembly has a f-number F#<2.9.

This limitation is the same as [2.1] and is disclosed for the same reasons discussed above. *Id.*

8. Claim 22

[22.0] The lens assembly of claim 21, wherein lens element L_{1_1} has a concave image-side surface.

This limitation is the same as [6.0] and is disclosed for the same reasons discussed above. *Id.*

9. Claim 23

[23.0] The lens assembly of claim 17, wherein the lens assembly has a f-number F#=2.8.

This limitation is rendered obvious for the same reasons discussed above in [2.1] where Ogino's Example 5 has been modified to support F#=2.8. *Id.*

E. Ground 3: Claims 3, 8, 19, and 24 are obvious under 35 U.S.C. § 103 over Ogino in view of Bareau, further in view of Kingslake.

1. Summary of Kingslake

Kinglake published in 1992 and is titled "Optics in Photography." APPL-1013, Cover. In Chapter 11 titled "The Brightness of Images," Kingslake indicates that "[t]he relation between the aperture of a lens and the brightness of the image produced by it … is often misunderstood, **yet it is of the greatest importance to the photographer who wishes to make the best use of the equipment**." *Id.*, p.104. Kingslake then states that "[t]he tremendous efforts of lens designers and manufacturers that have been devoted to the production of lenses of extremely high relative aperture **are an indication of the need that exists for brighter images and 'faster' lenses**." *Id.* Thus, as early as 1992, Kingslake indicates the need in the art to develop "faster" lenses (i.e., lower f-numbers) to produce brighter images. APPL-1003, ¶60. Lens designs with lower f-numbers were still in demand for use with digital image sensors in 2009. APPL-1025, pp.10-11 ("What is required is a lens system with a fairly low f/# to even theoretically achieve the sensor limited resolution.").

2. Reasons to combine Ogino, Bareau, and Kingslake

A POSITA would have found it obvious to modify Ogino's Example 5 lens assembly to support a lower f-number ("F#" or "Fno") based on (1) teachings from Ogino's other embodiments showing an f-number lower than Example 5, (2) teachings from Bareau and Wang of having an f-number of 2.8 **or less for small**

image sensors, and (3) the teaching from Kingslake indication a general desire in the art to develop brighter lens systems with lower f-numbers. *Id.*, ¶61; *see* APPL-1005, Figs. 8-13; APPL-1012, pp.3-4; APPL-1013, p.104; APPL-1024, 1:39-42. Such a modification of Example 5 would have been as simple as using lens design software and following the well-known lens design process explained in Fischer (APPL-1017) to find an optimized modification of Example 5 with a lower f-number consistent with Ogino's other embodiments. *Id.*

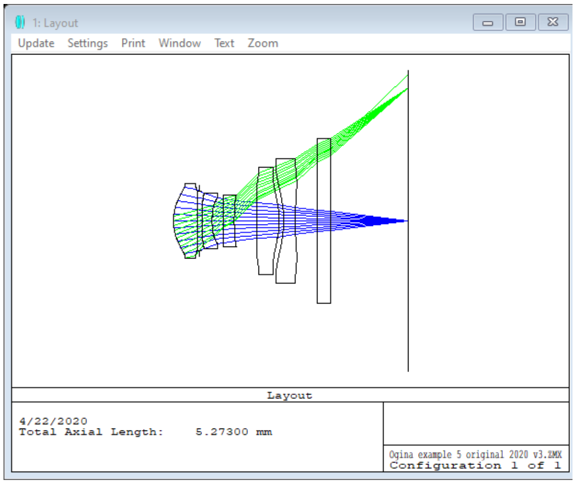
First, of Ogino's six examples, Example 5 has the highest F#=3.94. *See* APPL-1005, Figs. 8-13 (showing f-numbers of Examples 1-6). The f-numbers for Examples 1-3 and 6 (which all utilize a similar structure to Example 5), however, are much lower, respectively set at f-numbers 2.47, 2.46, 2.45, and 2.64. *See* APPL-1005, Figs. 8-10, 13. Based on this alone, a POSITA would have found it obvious to try to modify Ogino's Example 5 to see whether it would similarly support a lower f-number like F#=2.45. APPL-1003, ¶63.

Second, as discussed above in Bareau and Wang, POSITAs were well aware of modern cell phone specifications and the need to develop lens designs with f-numbers at or below 2.8 so that enough light would be provided to small sensor formats. *Id.*, ¶64. This general desire to achieve a lower f-number is confirmed by Kingslake which, as early as 1992, indicated the need for "faster" lenses: "The tremendous efforts of lens designers and manufacturers that have been devoted to

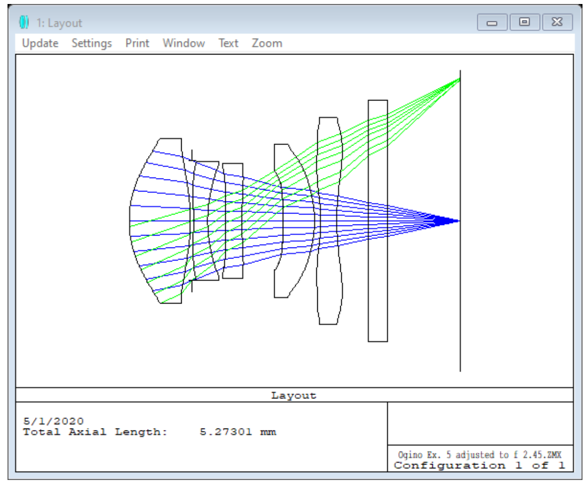
the production of lenses of extremely high relative aperture are an indication of **<u>the need that exists for brighter images and 'faster' lenses</u>**." APPL-1013, p.104. Due to this general desire for faster lenses to support smaller sensor formats, a POSITA would have been motivated modify Ogino's Example 5 lens to determine whether Example 5 could support a lower f-number like F#=2.45. APPL-1003, ¶63.

Following the lens design process which includes using lens design software (*see* APPL-1017, p.171-76), a POSITA would have reasonably expected to arrive at a usable design since Ogino's Example 3 (F#=2.45) and Example 5 share similar characteristics like lens groupings and lens shapes. *Id.*, ¶64. Also, given that Ogino's other examples all show lower f-numbers, a POSITA would have reasonably expected that Example 5's f-number could likewise be lower. *Id.* Proof that a POSITA would have had a reasonable expectation of success is provided below where Example 5 is modified to support an F#=2.45. *See id.*; *id.*, Fig. 3A.

Modifying Example 5 to achieve F#=2.45, as shown below, and using lens design software to find the best solution, a POSITA would have arrived at one possible lens design as shown below:



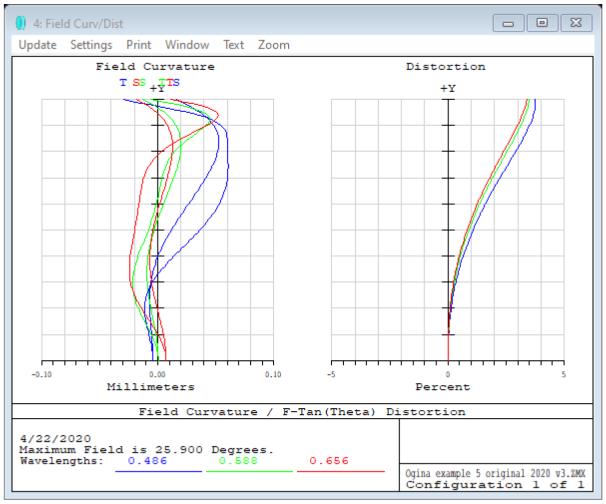
Ogino Example 5 (F#=3.94)



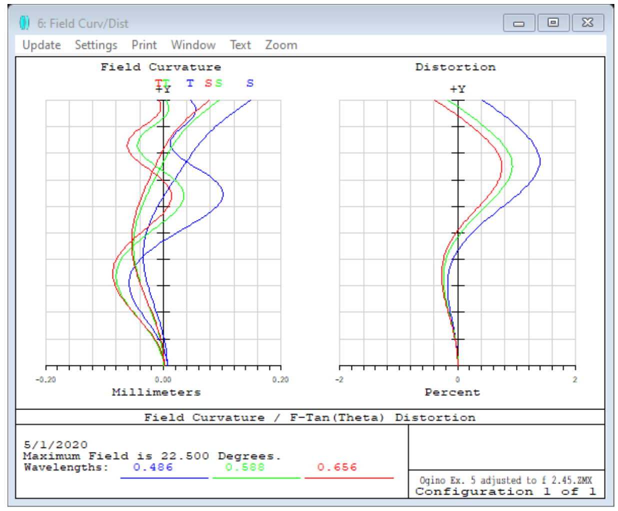
Example 5 modified with F#=2.45

See APPL-1003, ¶65. This modified version of Example 5 uses larger lens diameter for each lens, which, as taught in Walker, is one way to lower the f-number of a lens assembly since increasing a lens's diameter allows more light to pass through the system while maintaining a similar focal length. *Id.*

Modified Example 5 above supports an F#= 2.45 while maintaining similar performance characteristics and achieving higher relative illumination when compared to the original Example 5 design. *Id.*, ¶66. This is shown by comparing the field curves and relative illumination plots below:

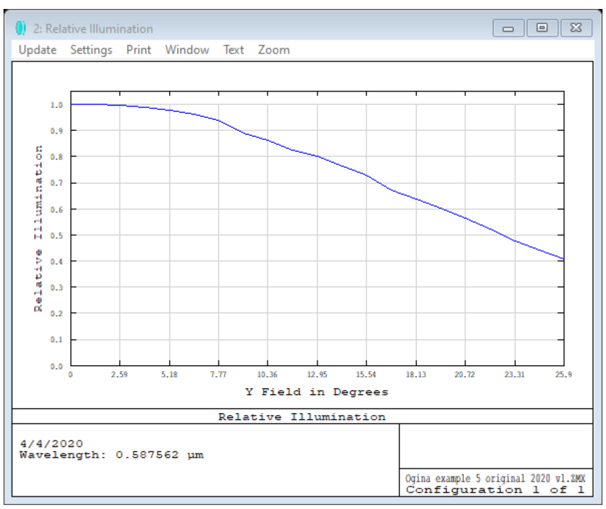


Ogino Example 5 (F#=3.94)

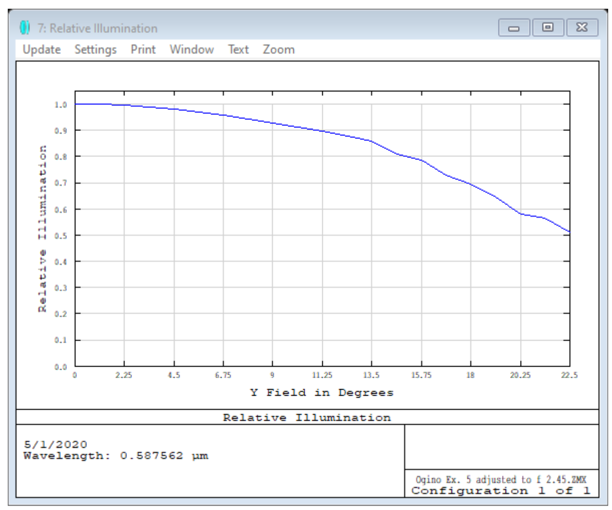


Example 5 modified with F#=2.45

See id.



Relative Illumination of Ogino Example 5 (F#=3.94)



Relative Illumination of Example 5 modified with F#=2.45

See id.

Ogino modified for a lower f-number continues to meet all of the limitations of claim 1. *Id.*, ¶67. Thus, a POSITA would have found it obvious, desirable, and predictable to lower the f-number of Ogino's Example 5 based on the teachings of

the other embodiments and as shown in Dr. Sasián's declaration, would have found reasonable success in achieving such a result. *Id.*

The following analysis describes how modifying Ogino's Example 5 to support a lower f-number renders obvious claims 3, 8, 19, and 24 of the '897 Patent. A corresponding claim chart is contained in Dr. Sasián's expert declaration. *See* APPL-1003, pp.72-75.

3. Claim 3

[3.0] The lens assembly of claim 1, wherein the TTL is equal or smaller than 6.0 mm

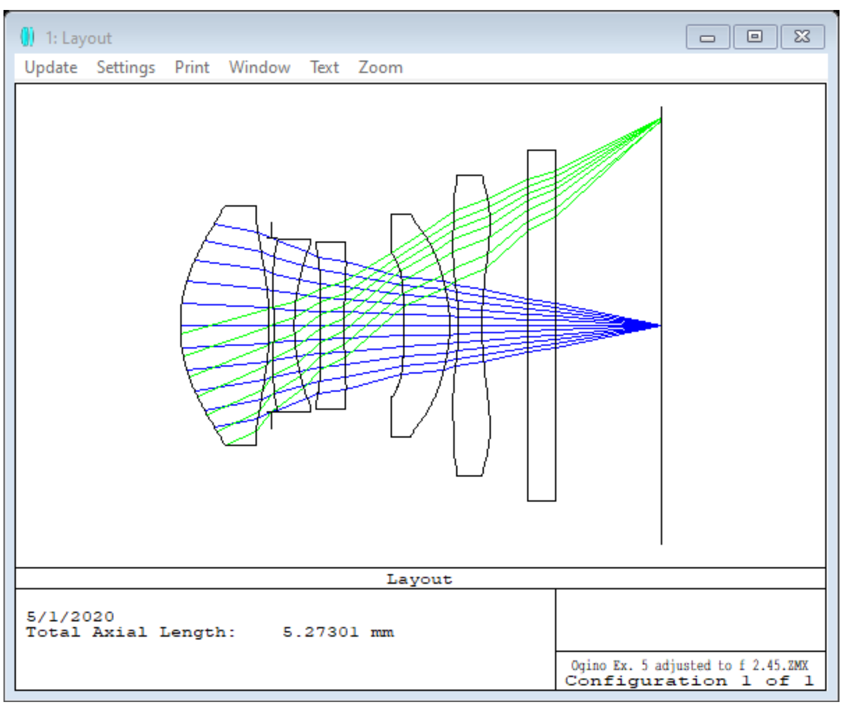
Ogino discloses this limitation because, as shown in [1.2], the Example 5 lens assembly has a TTL with the cover glass element of 5.273 mm which is less than 6.0 mm. In the modification above where Example 5 supports F#=2.45, the TTL is maintained to 5.273 mm as in Example 5 unmodified. *See id.*, p.72, Appendix, Fig. 3A. Thus, Ogino's Example 5 modified to support a lower F# of 2.45 renders this limitation obvious. *Id.*, p.72

[3.1] and wherein lens element L_{1_1} has an image-side surface diameter between 2.3 mm and 2.5 mm.

Ogino's Example 5 modified to support a lower f-number renders this limitation obvious. *Id.* As shown above, a POSITA would have found it obvious to modify Example 5 to achieve a telephoto lens with a lower f-number. *Id.* A POSITA would have found this modification to be both predictable and desirable

due to Ogino's other disclosed embodiments supporting lower f-numbers (*see* APPL-1005, Figs. 8-13), the teaching of Bareau and Wang indicating a desire for cell phone lenses with lower f-number for smaller sensors (*see* APPL-1012, pp.3-4; APPL-1024, 1:39-42), and the teachings on Kingslake indicating a general desire among POSITAs to design faster lenses (*see* APPL-1013, p.104). APPL-1003, p.72.

Further, as also discussed above, a POSITA would have understood that one way to reduce the f-number of a lens design is to make the lens diameters larger so that more light can pass through the system. *Id.* This is represented in the modification of Example 5 below that supports F#=2.45. Corresponding data is provided in the Appendix.



See id., p.73.

According to the data in the Appendix for this modification (*see id.*, Fig. 3D), the semi-diameter for the image-side surface of L1 (i.e., L_{1_1}) is 1.170 mm. *See id.*, Appendix, Fig. 3D (semi-diameter for surface 2). This yields a diameter of 2.34 mm, which falls between the claimed ratio of 2.3 mm and 2.5 mm. *Id.*

Thus, Ogino's Example 5 modified to support a lower f-number renders this claim obvious. *Id.*, p.73.

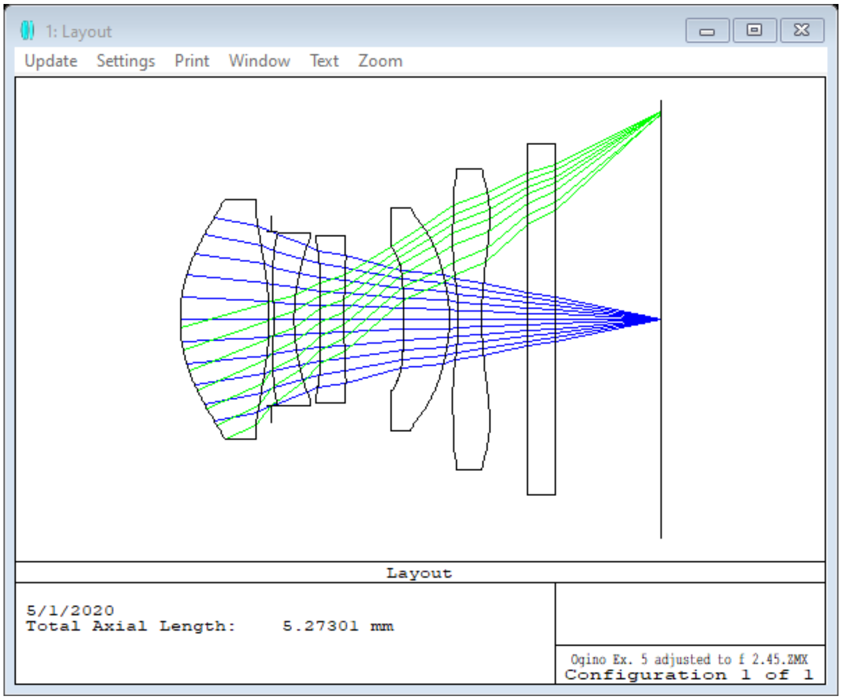
4. Claim 8

[8.0] The lens assembly of claim 5, wherein lens element L_{1_1} has a convex image-side surface.

Ogino's Example 5 modified to support a lower f-number renders this limitation obvious. *Id.* As shown above, a POSITA would have found it obvious to modify Example 5 to achieve a telephoto lens with a lower f-number. *Id.* A POSITA would have found this modification to be both predictable and desirable due to Ogino's other disclosed embodiments supporting lower f-numbers (*see* APPL-1005, Figs. 8-13), the teaching of Bareau and Wang indicating a desire for cell phone lenses with lower f-number for smaller sensors (see APPL-1012, pp.3-4; APPL-1024, 1:39-42), and a general desire among POSITAs to design faster lenses (*see* APPL-1013, p.104). APPL-1003, p.73.

Further, as also discussed above, a POSITA would have understood that one way to reduce the f-number of a lens design is to make the lens diameters larger so

that more light can pass through the system. *Id.* This is represented in the modification of Example 5 below that supports F#=2.45:



See id.

In this modified version of Example 5, the diameters of the lens elements and aperture have been slightly increased from the F#=2.8 design, which a POSITA would know would allow more light to enter the system. *Id.* The radius of curvature for the image-side surface of L1 was also changed from concave to convex to allow the L1 lens to better focus incoming light, to provide a thicker edge for easier manufacturing (*see* APPL-1007, p.7) while maintaining its original focal length as much as possible. APPL-1003, pp.74-75.

The L1 lens in the modification above has an rd of 1.607 for the object-side surface and an rd of -2.944 on the image-side surface. *Id.* The L1 lens therefore is

convex on both the object- and image-side surfaces. *Id.* Thus, Ogino's Example 5 modified to support a lower f-number renders this claim obvious. *Id.*, p.75.

5. Claim 19

[19.0-19.1] The lens assembly of claim 17, wherein the TTL is equal or smaller than 6.0 mm and wherein lens element L_{1_1} has an image-side surface diameter between 2.3 mm and 2.5 mm

This limitation is the same as [2.0-2.1] and is disclosed for the same reasons discussed above. *Id.*

6. Claim 24

[24.0] The lens assembly of claim 21, wherein lens element L1_1 has a convex image-side surface.

This limitation is the same as [8.0] and is disclosed for the same reasons discussed above. *Id.*

F. Ground 4: Claims 16 and 30 are obvious under 35 U.S.C. § 103 over Chen in view of Iwasaki, further in view of Beich.

1. Summary of Chen

Chen is directed to "an optical imaging lens set of five lens elements for use in mobile phones, in cameras, in tablet personal computers, or in personal digital assistants (PDA)." APPL-1020, 1:16-19. Chen's Example 1 is particularly relevant to claims 16 and 30 of the '897 Patent and is reproduced below:

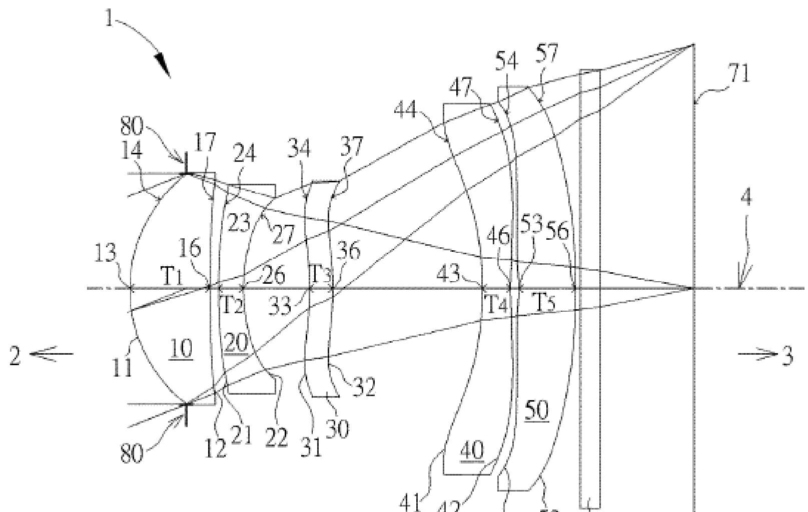


FIG. 6

Id., Fig. 6.

The prescription table describing Example 1 providing the thickness and spacing of each element along the optical axis and the focal length of each lens is similarly provided in Fig. 24:

First Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.565	0.855	T_1	1.545	55.987	2.975
		34.464	0.088	G_{12}			
21	Second Lens	6.079	0.264	T_2	1.642	22.409	-4.568
22		1.955	0.704	G_{23}			
31	Third Lens	-3.412	0.249	T_3	1.545	55.987	122.164
32		-3.330	1.598	G_{34}			
41	Fourth Lens	-4.283	0.310	T_4	1.545	55.987	-6.178
42		16.327	0.064	G_{45}			
51	Fifth Lens	-61.049	0.619	T_5	1.642	22.409	15.559
52		-8.680	0.050	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	1.007				
71	Image Plane	INFINITY					

Id., Fig. 24.

According to Chen, Example 1 has a focal length (f) of 6.582 mm, a total track length (TTL) of 6.0187 mm, and an f-number (Fno.) of 2.6614. *See id.*, 10:9-11, Fig. 42 (col. 1). Further, as discussed above in relation to the ’897 Patent, Chen similarly provides the sag equation and aspheric coefficients for Example 1 that can likewise be used to determine the edge thickness of each lens element. *Id.*, 9:49-67, Fig. 41.

2. Summary of Iwasaki

Similar to Chen and the ’897 Patent, Iwasaki discloses “a fixed focus imaging lens for forming optical images of subjects” that it is designed for use in portable devices such as “a digital still camera, a cellular telephone with a built in camera, a PDA (Personal Digital Assistant), a smart phone, a tablet type terminal, and a portable gaming device.” APPL-1009, 1:18-26. Iwasaki’s lens system is also similarly designed to meet a “demand for miniaturization of the entirety of the photography devices as well as imaging lenses to be mounted there on” and to meet a “demand for high resolution and high performance of imaging lenses.” *Id.*, 1:36-41.

All of Iwasaki’s embodiments are telephoto lenses, which is defined by the ratio of the total track length over the focal length of the lens system being less than one. *See id.*, 8:7-13; APPL-1006, p.169 (defining “telephoto ratio” as the focal length being longer than the overall lens length). Examples 1 and 2 of Iwasaki

maintain this ratio by using a thinner cover glass element of 0.145 mm rather than using 0.210 mm or 0.300 mm thick cover glass used in Examples 3 and 4. *See* APPL-1009, Tables 1, 3, 5, 7. Despite Iwasaki's embodiments using cover glass of various thicknesses, the purpose remains the same as disclosed in Chen to "protect[] the imaging surface and an infrared cutoff filter." APPL-1009, 6:8-9. Thus, Iwasaki teaches a POSITA that a thinner cover glass element can be used in a lens system to both reduce the total length while providing the same benefit of protecting the sensor and filtering infrared light. APPL-1003, ¶73.

3. Reasons to combine Chen and Iwasaki

A POSITA would have found it obvious and desirable to modify Chen's Example 1 lens system with Iwasaki's teaching of using a 0.145 mm cover glass element in a telephoto lens system. Such a combination would have both maintained the presence of a cover glass element in Example 1—for protecting the sensor and filtering infrared light, which Chen already teaches—while beneficially further reducing the total length of the lens system as indicated by Iwasaki. *See* APPL-1009, 1:57-60 ("[D]emand for shortening of the total lengths of lenses is increasing for imaging lenses which are employed in devices such as smart phones and tablet terminals, which are becoming progressively thinner."); APPL-1003, ¶74.

A POSITA would have been well aware that this modification simply required substituting the 0.210 mm cover glass element already present in Chen's Example 1 with a 0.145 mm element as taught in Iwasaki and shifting the location of the image plane to correct for the thinner cover glass element (i.e., focus shift). *Id.*, ¶¶74-75. This simple substitution would have been understood to yield the same predictable result as shown in Iwasaki of protecting the image sensor and filtering infrared light (which Chen teaches) while further reducing the total length of the lens system. *Id.* An example of this modification is provided in the Appendix and shows that the total length of Example 1 with a 0.145 mm cover glass element is reduced from 6.019 mm to 5.997 mm. *Id.*, Appendix, Fig. 4A.

Since Chen identifies the need for "improved imaging quality with reduced lens set size," a POSITA would have recognized that further reduction of the total length of each of Chen's embodiments could be achieved by simply using a thinner cover glass element, as shown in Iwasaki. *Id.*, ¶76. Using a lens design program such as Code V or Zemax, a POSITA could have modeled this replacement, as shown below, which does in fact meet both Chen's and Iwasaki's suggestion for including a cover glass element to filter infrared light. *Id.*, Appendix. Thus, a POSITA would have expected and, as shown below, would have been successful in reducing the thickness of Chen's Example 1 cover glass from 0.210 mm as shown in Fig. 24 to 0.145 mm as shown in Iwasaki's Examples 1 and 2. *Id.*

4. Summary of Beich

Beich is directed to manufacturing considerations for “polymer optics,” which are optics “made of plastic and through the process of injection molding ….” APPL-1007, p.2. Such optics “provid[e] customized solutions to unique engineering and product problems.” *Id.* This “allow[s] the deployment of sophisticated devices with increasingly complex optics on a cost competitive basis.” *Id.*

Beich states that its purpose is to instruct lens designers of “best practices when working with a polymer optics manufacturer.” *Id.* While injection molded optics provide several advantages, Beich states that it remains important for designers “to understand the manufacturing process behind these solutions so that they can design their programs to leverage the technology.” *Id.* This leads to manufacturing considerations or “rules of thumb” based on the reality that “overall shape and tolerances of the optic will drive cost and manufacturability.” *Id.*, p.7. These rules of thumb consider several factors such as “thicker parts take longer to mold than thinner parts” and “[o]ptics with extremely thick centers and thin edges are very challenging to mold.” *Id.* Accordingly, Beich teaches that a “rule of thumb” for “Center Thickness to Edge Thickness Ratio” is “< 3:1”, i.e., the center thickness should be less than three times the edge thickness. *Id.*

Attribute	Rules of Thumb Tolerances
Radius of Curvature	± 0.50%
EFL	± 1.0%
Center Thickness	± 0.020mm
Diameter	± 0.020mm
Wedge (TIR) in the Element	< 0.010mm
S1 to S2 Displacement (across the parting line)	< 0.020mm
Surface Figure Error	≤ 2 fringes per 25.4mm (2 fringes = 1 wave @ 632nm)
Surface Irregularity	≤ 1 fringes per 25.4mm (2 fringes = 1 wave @ 632nm)
Scratch-Dig Specification	40-20
Surface Roughness (RMS)	≤ 100 Å
Diameter to Center Thickness Ratio	< 4:1
Center Thickness to Edge Thickness Ratio	< 3:1
Part to Part Repeatability (in a one cavity mold)	< 0.50%

Table 2. Rules of thumb.

Desirable Center-to-Edge Thickness Ratio

Id. Consequently, a POSITA looking to implement optical element specifications using injection molding methods would look to Beich for guidance on limitations and parameters that affect lens manufacturability.

5. *Reasons to combine Chen and Beich*

A POSITA would have combined the teachings of Chen and Beich because such a combination would have been nothing more than using Beich's "rules of thumb" to make design choices to aid in the manufacturability of Chen's Example 1 lens assembly. APPL-1003, ¶79, Specifically, a POSITA looking to manufacture Chen's Example 1 would have considered Beich's rule of thumb for maintaining a desirable center-to-edge thickness ratio for the L1 lens element, which would aid in selecting the lens's diameter to maintain sufficiently uniform thickness for easier manufacturing. *Id.* Applying Beich's manufacturing considerations to Example 1 in this way would have yielded the predictable result of the L1 lens maintaining a

center-to-edge thickness ratio of less than 3.0 as already taught by Chen's Example 1 design. *Id.*, Appendix, Fig. 4E (showing edge thickness data for L1 of 0.293 mm (from surface 3 to 4) yielding a ratio of 2.92 given that the lens center thickness is 0.855 mm).

As shown above in the prescription table for Chen's Example 1, the first lens L1 has a thickness of 0.855 millimeters. *See id.*, Fig. 24. While Chen does not discuss manufacturing or materials of its lens elements, a POSITA would have recognized that only a few methods and materials would have been used to craft such small aspheric components. APPL-1003, ¶80. One such method is to manufacture plastic lenses through injection molding, which is "the preferred polymer manufacturing technology for optical elements having a diameter smaller than 0.1 m and a thickness not greater than 3 cm." APPL-1019, p.34.14. In addition to size considerations, a POSITA would have recognized that the refractive index and Abbe number of the lens elements in Example 1 are within the range of values of plastic materials used in injection molding manufacturing. *See* APPL-1018, p.27.

Since Example 1 would preferably have been manufactured via injection molding, and to the extent that Chen does not provide manufacturing parameters, a POSITA would have looked to polymer injection molding references such as Beich, which "discuss[es] the polymer optics manufacturing process and

examine[s] the best practices to use when working with a polymer optics manufacturer." APPL-1007, p.2. According to Beich, lens manufactures rely on "rules of thumb," as discussed above, in manufacturing lens elements to maintain the ratio of center thickness to edge thickness to a value less than three ("< 3:1"). *Id.*, p.7. This is because "[o]ptics with extremely thick centers and thin edges are very challenging to mold." *Id.* The "center thickness" and "edge thickness" in Beich correspond to the "largest optical axis thickness L11" and the "circumferential edge thickness L1e" in the '897 Patent. APPL-1003, ¶81.

A POSITA would have recognized that Chen does not specify the diameters of its respective lens elements, thus leaving it as a design choice based on manufacturability. *Id.*, ¶82. The L1 lens in Example 1—with a thick center and edges that grow thinner as the lens diameter increases—is of the type, though, for which a POSITA would have sought to maintain a center-to-edge thickness of less than 3:1. *Id.* In other words, to maintain the desirable 3:1 ratio, a POSITA would have set a lens diameter so that the lens would function for its intended purpose of passing through all intended light rays and be easier to manufacture. *Id.* This is evidenced by the L1 lens, as originally designed, having an edge thickness of 0.293 as calculated by Zemax that thus yields a center-to-edge thickness ratio (0.855/0.293) of about 2.92. *See id.*, Appendix, Fig. 4E.

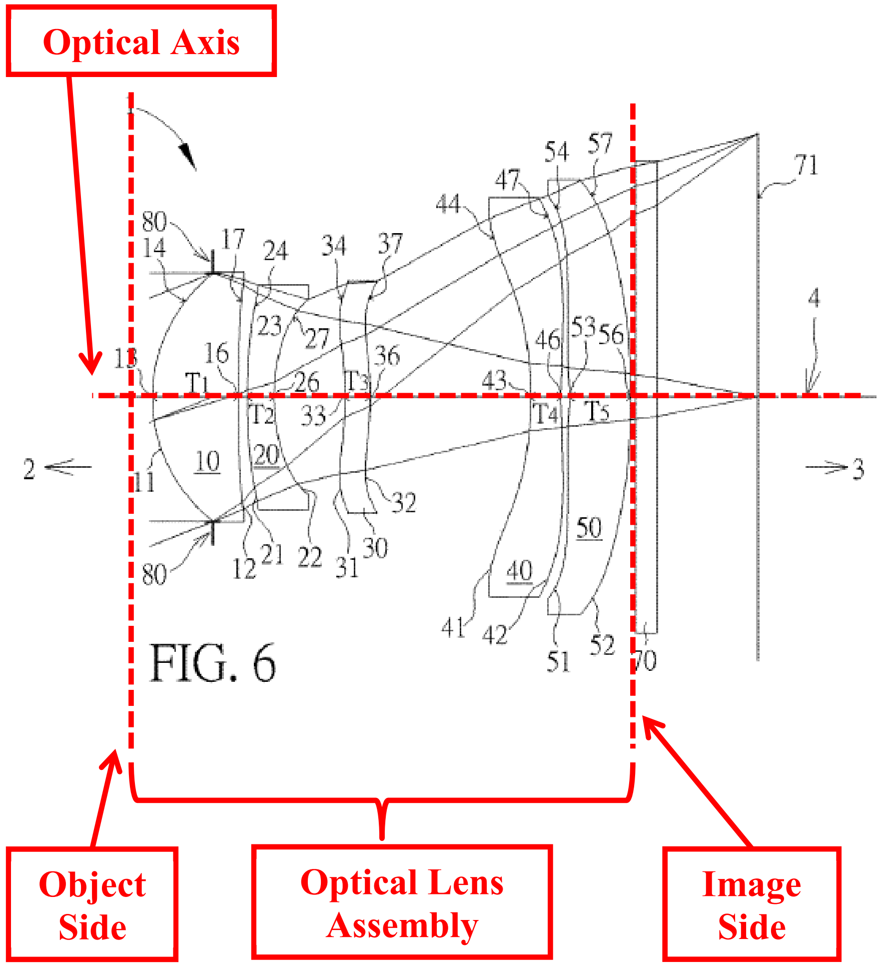
Thus, a POSITA looking to manufacture Chen's Example 1 lens system would have understood the benefit of applying the teachings of Beich, thereby resulting in an L1 lens in Chen's Example 1 with a diameter set for manufacturing so that the center-to-edge thickness ratio is maintained at less than 3, as provided for in Chen's original design. *Id.*, ¶83.

The following analysis describes how the combination of Chen, Iwasaki, and Beich renders obvious claims 16 and 30. Analysis for the claims from which claims 16 and 30 depend is also provided. A corresponding claim chart is in Dr. Sasián's expert declaration. *See* APPL-1003, pp.85-99.

6. Claim 16

[1.0] A lens assembly, comprising a plurality of lens elements arranged along an optical axis and spaced apart by respective spaces,

Chen discloses this limitation because it teaches a multi-lens system in Example 1 that includes a lens assembly "from an object side toward an image side in order along an optical axis [that] has a first lens element, a second lens element, a third lens element, a fourth lens element and a fifth lens element." APPL-1020, 1:42-48. Example 1 is represented in Fig. 6, which shows the five lens elements arranged in order from an object side to an image side along an optical axis:



APPL-1003, pp.85-86; APPL-1020, Fig. 6 (annotated). Thus, Chen's Example 1 teaches this limitation.

[1.1] wherein the lens assembly has an effective focal length (EFL),

As discussed above in the Claim Construction section, the term "effective focal length (EFL)" is means "*the focal length of a lens assembly*." As indicated in Fig. 42, the focal length (EFL) of Chen's Example 1 is 6.582 mm. APPL-1020, Fig. 42 (col. 1). Thus, Chen's Example 1 teaches this limitation. APPL-1003, p.86

[1.2] a total track length (TTL) of 6.5 millimeters or less

As discussed above, the term "total track length (TTL)" is construed to mean "*the length of the optical axis spacing between the object-side surface of the first lens element and one of: an electronic sensor, a film sensor, and an image plane corresponding to either the electronic sensor or a film sensor*."

The combination of Chen and Iwasaki renders this limitation obvious. *Id.* As established in Fig. 42 and discussed above, Chen's Example 1 has a TTL of 6.019 mm, just outside the claimed TTL value of 6.0 mm. *Id.* Example 1, though, uses a glass plate, IR filter 70 "placed between the image-side surface 52 of the fifth lens element 50 and the image plane 71" which filters "specific wavelength light (such as the infrared light) [from] reaching the image plane to adversely affect the imaging quality." APPL-1020, 7:42-46, 8:59-62, Fig. 24.

As discussed above in the Reasons to Combine and based on the teachings of Iwasaki, a POSITA would have found it obvious to use a thinner glass plate to filter infrared light since using a thinner glass plate would have been known to be beneficial to both provide the same benefits of filter infrared light while also reducing the total length of the lens. APPL-1003, p.87. For example, in Iwasaki's first two embodiments, an IR filter of 0.145 mm is used rather than the 0.210 mm filter used in the fourth embodiment. *Id.*; APPL-1009, Tables 1, 3. Because a POSITA was aware that the glass plate could be of various thickness and because Chen teaches the need for "improved imaging quality with reduced lens set size," a

POSITA would have been motivated to further reduce the total length (i.e., size) of Chen's embodiments. APPL-1003, p.88.

A POSITA replacing the 0.210 mm glass plate in Chen's Example 1 with a 0.145 mm glass plate as taught in Iwasaki, would have understood that the image plane would shift toward the object side to compensate for both thinner glass and the resulting change in focus shift. *Id.* The focus shift of a glass plate can be approximated using the following equation:

$$\frac{index\ of\ refraction - 1}{index\ of\ refration} \times thickness$$

As discussed above, the TTL of Example 1 is 6.019 mm. *See id.*, Fig. 42. Shifting the image plane in Example 1 by using an IR filter of 0.145 mm obviously results in a lower TTL of 5.985 mm. *See id.*, Appendix, Fig. 4A. Thus, Chen's Example 1 renders this limitation obvious. *Id.*, p.88.

[1.3] and a ratio TTL/EFL<1.0,

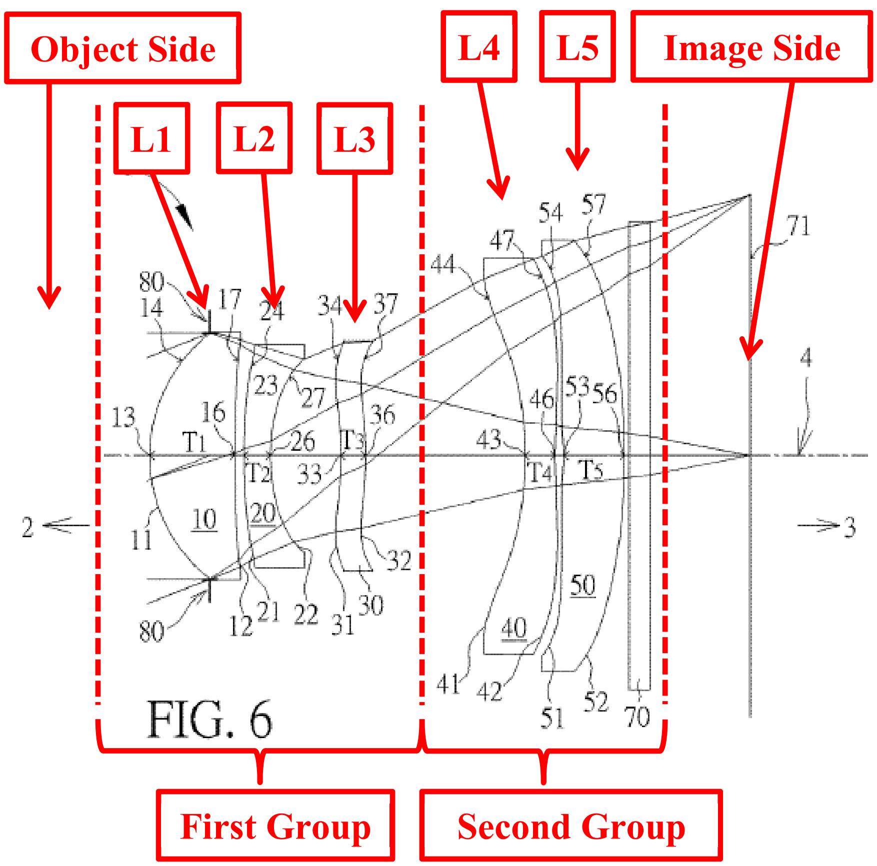
The combination of Chen and Iwasaki renders this limitation obvious because as shown above in [1.1] and [1.2], Example 1 has a total track length (TTL) of 5.985 mm when modified with a thinner cover glass element as provided in Iwasaki and an effective focal length (EFL) of 6.582 mm. *See id.*, Fig. 42 Chen thus meets this claimed ratio as shown below:

$$\frac{TTL}{EFL} < 1.0 \rightarrow \frac{5.985\ mm}{6.582\ mm} = 0.909 < 1.0$$

Thus, Chen's Example 1 lens system with a thinner cover glass element renders this limitation obvious. APPL-1003, p.88-89.

[1.4] wherein the plurality of lens elements includes, in order from an object side to an image side, a first group comprising lens elements L_{1_1}, L_{1_2} and L_{1_3} with respective focal lengths f_{1_1}, f_{1_2} and f_{1_3} and a second group comprising lens elements L_{2_1} and L_{2_2},

Chen discloses this limitation because the Example 1 lens assembly includes a first lens group with three lens elements (L1-L3) and a second lens group with two lens elements (L4 and L5):



APPL-1003, p.89; APPL-1020, Fig. 6 (annotated).

Each of the lens elements L1, L2, and L3 in Chen's Example 1 has a respective focal length as shown in Fig. 24 below:

First Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.565	0.855	T_1	1.545	55.987	2.975
		34.464	0.088	G_{12}			
21	Second Lens	6.079	0.264	T_2	1.642	22.409	-4.568
22		1.955	0.704	G_{23}			
31	Third Lens	-3.412	0.249	T_3	1.545	55.987	122.164
32		-3.330	1.598	G_{34}			
41	Fourth Lens	-4.283	0.310	T_4	1.545	55.987	-6.178
42		16.327	0.064	G_{45}			
51	Fifth Lens	-61.049	0.619	T_5	1.642	22.409	15.559
52		-8.680	0.050	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	1.007				
71	Image Plane	INFINITY					

Focal Length of L1

Focal Length of L2

Focal Length of L3

APPL-1003, p.90; APPL-1020, Fig. 24 (annotated).

Thus, Chen's Example 1 lens assembly teaches this limitation.

[1.5] wherein the first and second groups of lens elements are separated by a gap that is larger than twice any other gap between lens elements,

Chen discloses this limitation because the Example 1 lens assembly includes a gap between the first group (L1-L3) and the second group (L4-L5) that is twice larger than any other gap. *Id.*, p.92. First, as shown above in [1.3] Example 1 includes a first group of lens elements L1-L3 and a second group of lens elements L4-L5. *Id.*, pp.90-91.

As shown above, the gap between the first and second groups in Example 1 is the space between the third and fourth lens elements. *Id.* This and the other gaps between lens elements are provided in Fig. 24:

First Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.565	0.855	T_1	1.545	55.987	2.975
		34.464	0.088	G_{12}			
21	Second Lens	6.079	0.264	T_2	1.642	22.409	-4.568
22		1.955	0.704	G_{23}			
31	Third Lens	-3.412	0.249	T_3	1.545	55.987	122.164
32		-3.330	1.598	G_{34}			
41	Fourth Lens	-4.283	0.310	T_4	1.545	55.987	-6.178
42		16.327	0.064	G_{45}			
51	Fifth Lens	-61.049	0.619	T_5	1.642	22.409	15.559
52		-8.680	0.050	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	1.007				
71	Image Plane	INFINITY					

Gaps between other lens elements

Gap between L3 and L4

APPL-1003, p.91; APPL-1020, Fig. 24 (annotated). Because the gap between L3 and L4 is 1.598 mm, it is twice larger than any of the other gaps between lens elements. APPL-1003, p.91. Thus, Chen's Example 1 teaches this limitation. *Id.*

[1.6] wherein lens element L_{1_1} has positive refractive power and lens element L_{1_2} has negative refractive power,

Chen discloses this limitation because the optical data for the Example 1 shows that the L1 lens element (i.e., L_{1_1}) has a positive focal length and the L2 lens element (i.e., L_{1_2}) has negative focal length:

First Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.565	0.855	T_1	1.545	55.987	2.975
		34.464	0.088	G_{12}			
21	Second Lens	6.079	0.264	T_2	1.642	22.409	-4.568
22		1.955	0.704	G_{23}			
31	Third Lens	-3.412	0.249	T_3	1.545	55.987	122.164
32		-3.330	1.598	G_{34}			
41	Fourth Lens	-4.283	0.310	T_4	1.545	55.987	-6.178
42		16.327	0.064	G_{45}			
51	Fifth Lens	-61.049	0.619	T_5	1.642	22.409	15.559
52		-8.680	0.050	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	1.007				
71	Image Plane	INFINITY					

Focal Length of L1

Focal Length of L2

APPL-1003, p.92; APPL-1020, Fig. 24 (annotated). A POSITA would have understood a positive focal length to yield a positive refractive power and a negative focal length to yield a negative refractive power since refractive power is defined as the inverse of the focal length. *See* APPL-1010, p.159, footnote.

Thus, Chen's Example 1 teaches this limitation. APPL-1003, p.93.

[1.7] and wherein lens elements L_{2_1} and L_{2_2} have opposite refractive powers.

Chen discloses this limitation because the optical data for Example 1 shows that the L4 lens element (i.e., L_{2_1}) has a negative focal length and the L5 lens element (i.e., L_{2_2}) has positive focal length:

First Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.565	0.855	T_1	1.545	55.987	2.975
		34.464	0.088	G_{12}			
21	Second Lens	6.079	0.264	T_2	1.642	22.409	-4.568
22		1.955	0.704	G_{23}			
31	Third Lens	-3.412	0.249	T_3	1.545	55.987	122.164
32		-3.330	1.598	G_{34}			
41	Fourth Lens	-4.283	0.310	T_4	1.545	55.987	-6.178
42		16.327	0.064	G_{45}			
51	Fifth Lens	-61.049	0.619	T_5	1.642	22.409	15.559
52		-8.680	0.050	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	1.007				
71	Image Plane	INFINITY					

Focal Length of L4

Focal Length of L5

Id.; APPL-1020, Fig. 24 (annotated).

A POSITA would have understood a positive focal length to indicate a positive refractive power and a negative focal length to indicate a negative refractive power since refractive power is defined as the inverse of the focal length. *See* APPL-1003, pp.93-94; APPL-1010, p.159, footnote. Thus, Chen's Example 1 teaches this limitation. APPL-1003, p.94.

[2.0] The lens assembly of claim 1, wherein the TTL is equal or smaller than 6.0 mm and

The combination of Chen and Iwasaki renders this limitation obvious because, as discussed above in [1.2], Chen's Example 1 with a thinner cover glass as taught in Iwasaki shows a TTL of 5.985 mm. *See id.*, Appendix, Fig. 4A. Thus, the combination of Chen's Example 1 with a thinner glass plate as taught in Iwasaki renders this limitation obvious. *Id.*

[2.1] wherein the lens assembly has a f-number F#<2.9.

Chen discloses this limitation because Example 1 has an f-number (F#) of 2.661. APPL-1020, 13:17-18, Fig. 42. Thus, Chen's Example 1 teaches this limitation. APPL-1003, p.46.

[16.0] The lens assembly of claim 2, wherein the lens assembly further includes a ratio between a largest optical axis thickness L11 and a circumferential edge thickness L1e of lens element L_{1_1} of L11/L1e<3.

The combination of Chen and Beich renders this limitation obvious. A POSITA would have understood that the L1 lens in Chen's Example 1 is design so that the center-to-edge thickness would be less than three when manufactured. *Id.*, pp.94-95. In fact, the Zemax model of Example 1 provided by Dr. Sasián shows that the L1 lens has a center thickness of 0.855 mm (*see* Fig. 24), an edge thickness of 0.293 mm, and a center-to-edge thickness ratio of 2.92. *Id.*; *see also id.*, Appendix, Fig. 4E. Based on the teaching of Beich, a POSITA would have sought to limit the diameter of the first lens so that this would be maintained for easier plastic injection molding. *Id.*, p.94; APPL-1007, p.7.

In more detail and as discussed above, the ’897 Patent states that the center-to-edge thickness ratio can be determined by using the thickness of the first lens (i.e., L11), the aspheric data provided for each surface of the first lens, and the radius of the first lens. *See* APPL-1001, 5:21-23(“Using the data from row #2 in Tables 1 and 2, L1e in lens element 102 equals 0.297 mm, yielding a center-to-edge thickness ratio L11/ L1e of 3.01.”).

Using this same method with the sag equation, the thickness of the first lens, the aspheric data for each surface of the first lens, and the diameter of the first lens, a POSITA would have recognized that the same ratio can be determined for Chen’s Example 1. APPL-1003, p.95. In Example 1, the thickness of the first lens is 0.855 mm as shown in Fig. 24 and the aspheric data for each surface of the first lens is provided in the columns marked “11” and “12” in Fig. 25. APPL-1009, Figs. 24-25. Chen, however, does not provide a diameter for the first lens. APPL-1003, p.95

For this reason, a POSITA considering the manufacturability of Chen would have determined the diameter of the first lens such that the lens would cover the aperture (to allow light passing through the aperture to enter the lens system) but would also be easy to manufacture. APPL-1003, p.97. A shown in the Zemax calculated model in Dr. Sasián’s Appendix, a POSITA would have determined the thickness of the edge of the L1 lens to be 0.293 mm (*see id.*, Appendix Fig. 4E) yielding a center-to-edge thickness ratio of the L1 lens in Chen’s Example 1 to be

2.92 (i.e., 0.855/0.293) which is less than the claimed ratio of three and consistent with Beich's teaching. *Id.*, p.95.

Because Example 1 already meets Beich's preferred center-to-edge thickness ratio of less than 3.0 at the diameter that supports the lens system, a POSITA would have understood the need to maintain the diameter so that Beich's center-to-edge thickness ratio would be maintained since this ratio increases as the diameter increases due to the shape of the lens. *Id.* Put another way, as the diameter of the first lens in Example 1 increases, the edge becomes thinner due to the shape. *Id.* In cases like this, according to Beich, "[o]ptics with extremely thick centers and thin edges are very challenging to mold." APPL-1007, p.7. Beich thus suggests that for ease of manufacturing, the center-to-edge thickness ratio should be maintained at less than 3:1, which Chen's Example 1 already provides. APPL-1003, p.96.

A POSITA knowing of this issue with manufacturability would have thus been motivated to constrain the diameter of the first lens so that this desirable ratio would be maintained. *Id.* Based on these teaching from Beich, a POSITA using the sag equation and the data provided for Example 1 in Chen would have determined the diameter of the first lens that could be achieved while still maintaining a desirable center-to-edge thickness, as provided for in Chen's Example 1 design. *Id.* Consequently, because a POSITA would have found it obvious to set the diameter

of the first lens in Chen's Example 1 to simply maintain the center-to-edge thickness ratio at less than 3 as already provided, the combination of Chen's Example 1 lens design and Beich teachings renders this limitation obvious. *Id.*

7. Claim 30

[17.0] A lens assembly, comprising: a plurality of lens elements arranged along an optical axis and spaced apart by respective spaces,

This limitation is the same as [1.0] and is disclosed for the same reasons discussed above. *Id.*, p.97.

[17.1] wherein the lens assembly has an effective focal length (EFL),

This limitation is the same as [1.1] and is disclosed for the same reasons discussed above. *Id.*

[17.2] wherein a lens system that includes the lens assembly plus a window positioned between the plurality of lens elements and an image plane

Chen discloses this limitation because the Example 1 lens system includes a filter 70 that "may be an infrared cut filter (IR cut filter), placed between the image-side surface 52 of the fifth lens element 50 and the image plane 71." APPL-1020, 7:42-46, Fig. 24. As shown in Chen's Fig. 24, the IR filter has a thickness of 0.210 mm, a refractive index of 1.517, and an Abbe No. of 64.167. *Id.*, Fig. 24. Iwasaki shows an IR filter of similar refractive index and Abbe No. but at 0.145 mm. *See* APPL-1009, Table 1, 3. These parameters are consistent with the parameters for the "window" set forth in each embodiment of the '897 Patent. *See*

APPL-1001, Tables 1, 3, 5. Thus, Chen, Iwasaki, and the ’897 Patent all utilize the same refractive material for the “window” as claimed. APPL-1003, p.97.

Thus, Chen’s Example 1 lens system with an IR filter positioned between the fifth lens element and the image plane teaches this limitation. *Id.*, p.98.

[17.3] has a total track length (TTL) of 6.5 millimeters or less,

This limitation is the same as [1.2] and is disclosed for the same reasons discussed above. *Id.*

[17.4] wherein a ratio TTL/EFL<1.0,

This limitation is the same as [1.3] and is disclosed for the same reasons discussed above. *Id.*

[17.5] wherein the plurality of lens elements includes, in order from an object side to an image side, a first group comprising lens elements L_{1_1}, L_{1_2} and L_{1_3} with respective focal lengths f_{1_2} and f_{1_3}, and a second group comprising lens elements L_{2_1} and L_{2_2},

This limitation is the same as [1.4] and is disclosed for the same reasons discussed above. *Id.*

[17.6] wherein lens element L_{1_1} has positive refractive power and lens element L_{1_2} has negative refractive power,

This limitation is the same as [1.6] and is disclosed for the same reasons discussed above. *Id.*

[17.7] wherein $1.2\times|f_{1\_3}|>|f_{1\_2}|>1.5\times f_{1\_1}$,

Chen discloses this limitation because the L1, L2, and L3 lenses in the Example 1 lens assembly meet the claimed expression as shown below. *Id.* As discussed in [1.4], the focal length f_{1_1} is 2.975 mm, the focal length f_{1_2} is -4.568 mm, and the focal length f_{1_3} is 122.164 mm. *Id.*; APPL-1020, Fig. 24. Applying these values to the claimed expression $1.2\times|f_{1\_3}|>|f_{1\_2}|>1.5\times f_{1\_1}$ yields:

$$1.2 \times |122.164| > |\text{-}4.568\ mm| > 1.5 \times 2.975\ mm$$

$$\rightarrow \mathbf{146.597\ \boldsymbol{mm} > \ 4.568\ \boldsymbol{mm}\ > 4.463\ \boldsymbol{mm}}$$

Thus, Ogino's Example 5 lens assembly teaches this limitation. *Id.*, p.99.

[17.8] and wherein lens elements L_{2_1} and L_{2_2} have opposite refractive powers.,

This limitation is the same as [1.7] and is disclosed for the same reasons discussed above. *Id.*

[18.0-18.1] The lens assembly of claim 17, wherein the TTL is equal or smaller than 6.0 mm and wherein the lens assembly has a f-number F#<2.9.

This limitation is the same as [2.0-2.1] and is disclosed for the same reasons discussed above. *Id.*

[30.0] The lens assembly of claim 18, wherein the lens assembly further includes a ratio between a largest optical axis thickness L11 and a circumferential edge thickness L1e of lens element L_{1_1} of L11/L1e<3.

This limitation is the same as [16.0] and is disclosed for the same reasons discussed above. *Id.*

X. CONCLUSION

For the reasons set forth above, Petitioner has established a reasonable likelihood that claims 1-6 and 8-30 of the ’897 Patent are unpatentable. Petitioner requests institution of an *inter partes* review and cancelation of these claims.

Respectfully submitted,

Dated: May 1, 2020

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CERTIFICATE OF WORD COUNT

Pursuant to 37 C.F.R. §42.24(d), Petitioner hereby certifies, in accordance with and reliance on the word count provided by the word-processing system used to prepare this petition, that the number of words in this paper is 13,811. Pursuant to 37 C.F.R. §42.24(d), this word count excludes the table of contents, table of authorities, mandatory notices under §42.8, certificate of service, certificate of word count, appendix of exhibits, and any claim listing.

Dated: May 1, 2020

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CERTIFICATE OF SERVICE

The undersigned certifies that, in accordance with 37 C.F.R. § 42.6(e) and 37 C.F.R. § 42.105, service was made on Patent Owner as detailed below. Patent Owner has authorized electronic service due to the United States Post Office suspending deliver to the address listed in accordance with 37 CFR § 42.105(a). *See* APPL-1027.

Date of service	May 1, 2020
Manner of service	Electronically: mafenster@raklaw.com, bwang@raklaw.com, jtsuei@raklaw.com, nrubin@raklaw.com
Documents served	Petition for *Inter Partes* Review of U.S. Patent No. 10,330,897; Petitioner's Exhibit List; Exhibits 1001–1027
Persons served	Marc A. Fenster, Benjamin T. Wang James S. Tsuei, Neil A. Rubin Russ August & Kabat 12424 Wilshire Blvd., 12th Floor Los Angeles, CA 90025

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US010330897B2

(12) **United States Patent**
Dror et al.

(10) **Patent No.: US 10,330,897 B2**
(45) **Date of Patent: *Jun. 25, 2019**

(54) **MINIATURE TELEPHOTO LENS ASSEMBLY**

(71) Applicant: **Corephotonics Ltd.**, Tel-Aviv (IL)

(72) Inventors: **Michael Dror**, Nes Ziona (IL); **Ephraim Goldenberg**, Ashdod (IL); **Gal Shabtay**, Tel Aviv (IL)

(73) Assignee: **Corephotonics Ltd.**, Tel Aviv (IL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/976,391**

(22) Filed: **May 10, 2018**

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(51) **Int. Cl.**
G02B 13/00 (2006.01)
G02B 13/02 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G02B 13/0045*** (2013.01); ***G02B 1/041*** (2013.01); ***G02B 9/60*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC .. G02B 13/0045; G02B 9/60; G02B 27/0025; G02B 5/005; G02B 13/02; G02B 1/041;
(Continued)

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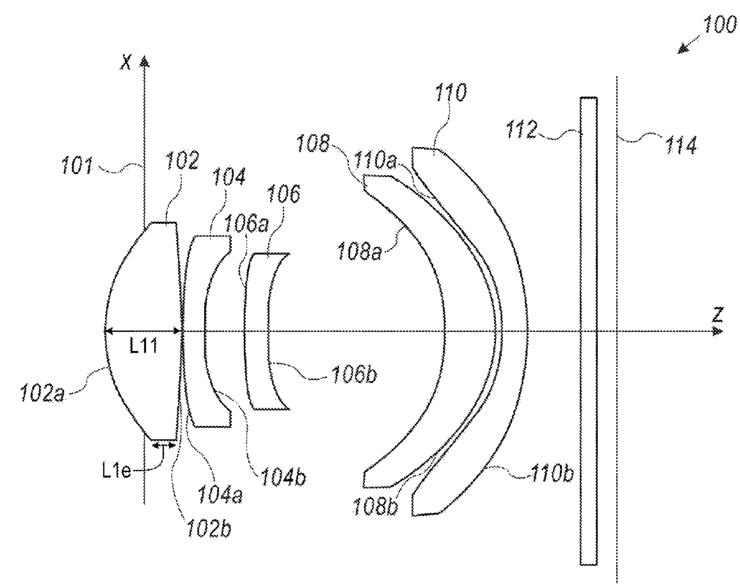
(57) **ABSTRACT**

An optical lens assembly includes five lens elements and provides a TTL/EFL<1.0. In an embodiment, the focal length of the first lens element f1<TTL/2, an air gap between first and second lens elements is smaller than half the second lens element thickness, an air gap between the third and fourth lens elements is greater than TTL/5 and an air gap between the fourth and fifth lens elements is smaller than about 1.5 times the fifth lens element thickness. All lens elements may be aspheric.

30 Claims, 6 Drawing Sheets



Related U.S. Application Data

No. 15/418,925, filed on Jan. 30, 2017, now Pat. No. 9,857,568, which is a continuation of application No. 15/170,472, filed on Jun. 1, 2016, now Pat. No. 9,568,712, which is a continuation of application No. 14/932,319, filed on Nov. 4, 2015, now Pat. No. 9,402,032, which is a continuation of application No. 14/367,924, filed as application No. PCT/IB2014/062465 on Jun. 20, 2014, now abandoned.

(60) Provisional application No. 61/842,987, filed on Jul. 4, 2013.

(51) **Int. Cl.**

G02B 9/60	(2006.01)
G02B 27/00	(2006.01)
G02B 1/04	(2006.01)
G02B 27/64	(2006.01)
G02B 5/00	(2006.01)
G02B 9/00	(2006.01)
H04N 101/00	(2006.01)

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CPC ***G02B 13/02*** (2013.01); ***G02B 27/0025*** (2013.01); ***G02B 27/646*** (2013.01); *G02B 5/005* (2013.01); *G02B 9/00* (2013.01); *G02B 13/002* (2013.01); *H04N 2101/00* (2013.01); *H04N 2201/00* (2013.01); *Y10T 29/4913* (2015.01)

(58) **Field of Classification Search**
CPC G02B 13/002; G02B 9/00; G02B 27/646; H04N 2201/00; Y10T 29/4913
USPC 359/714, 739, 740, 763, 764
See application file for complete search history.

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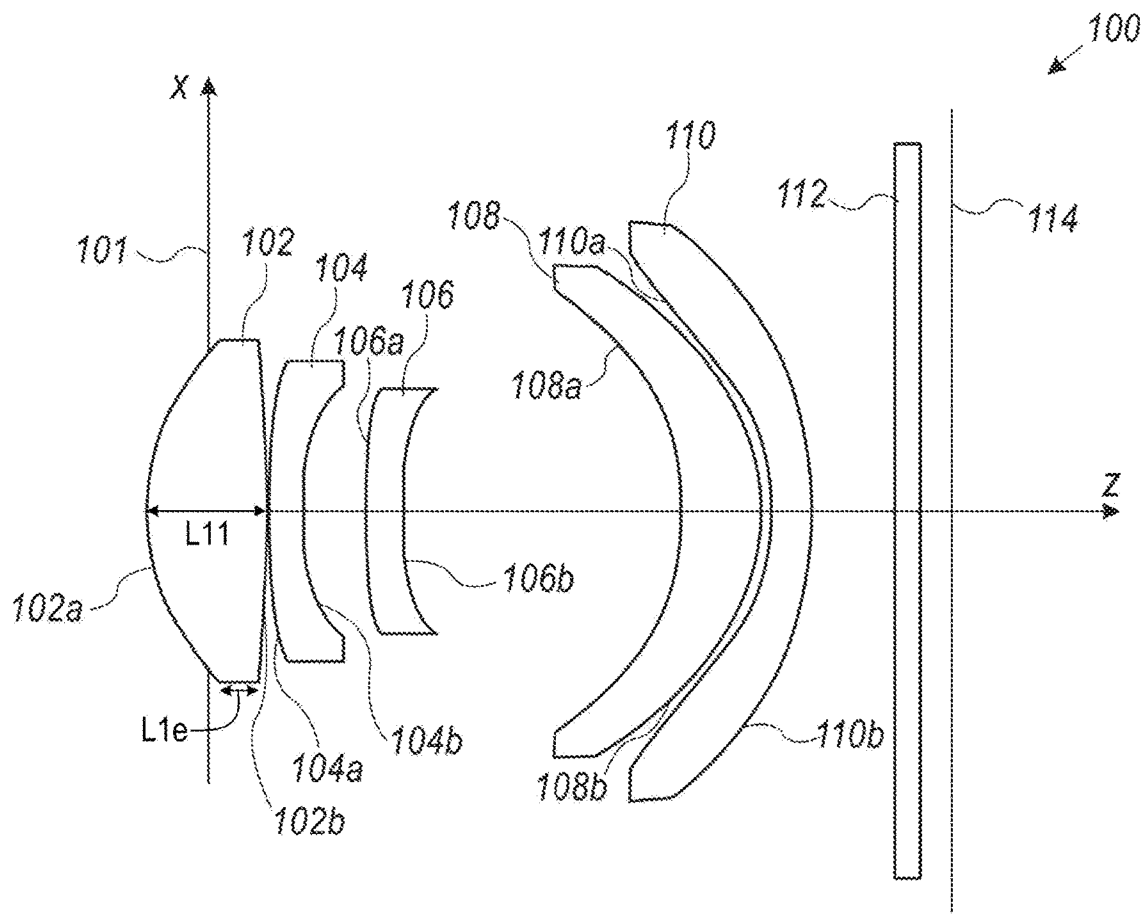
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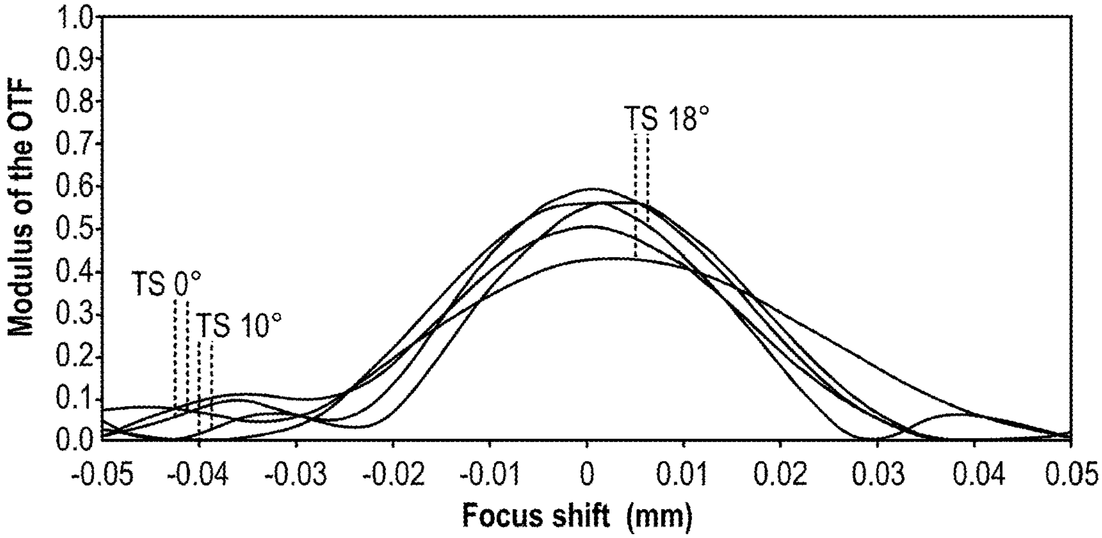
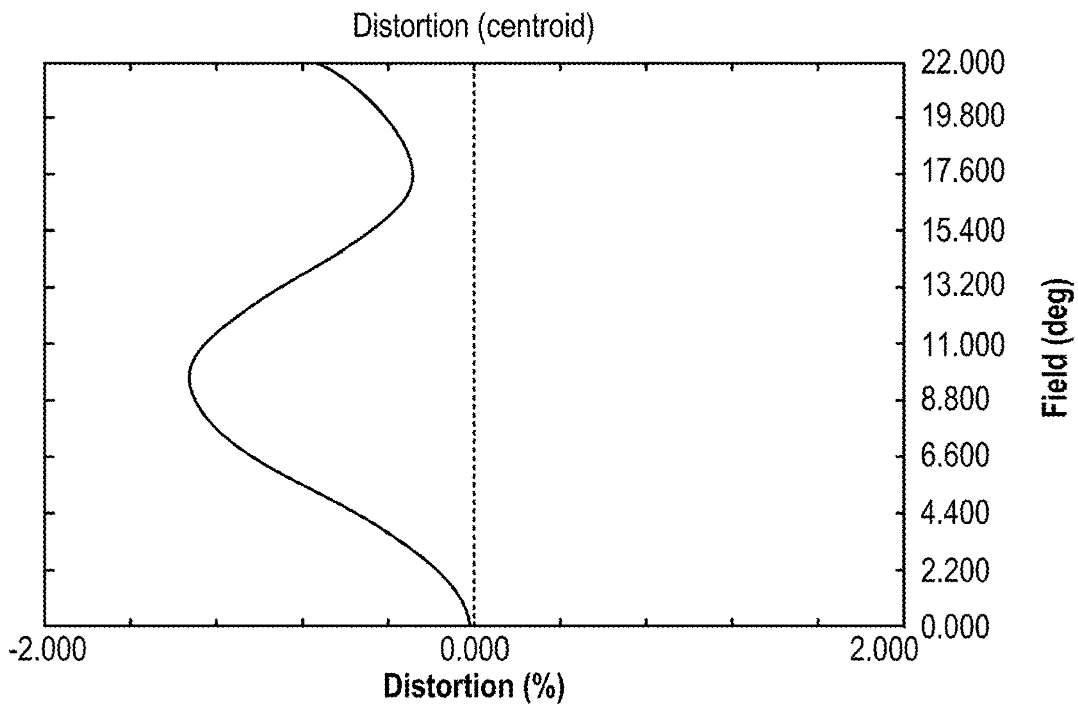
X
110
112
114
108
110a
101
102
104
106
106a
108a
Z
L11
106b
102a
110b
104b
L1e
104a
108b
102b

FIG. 1A



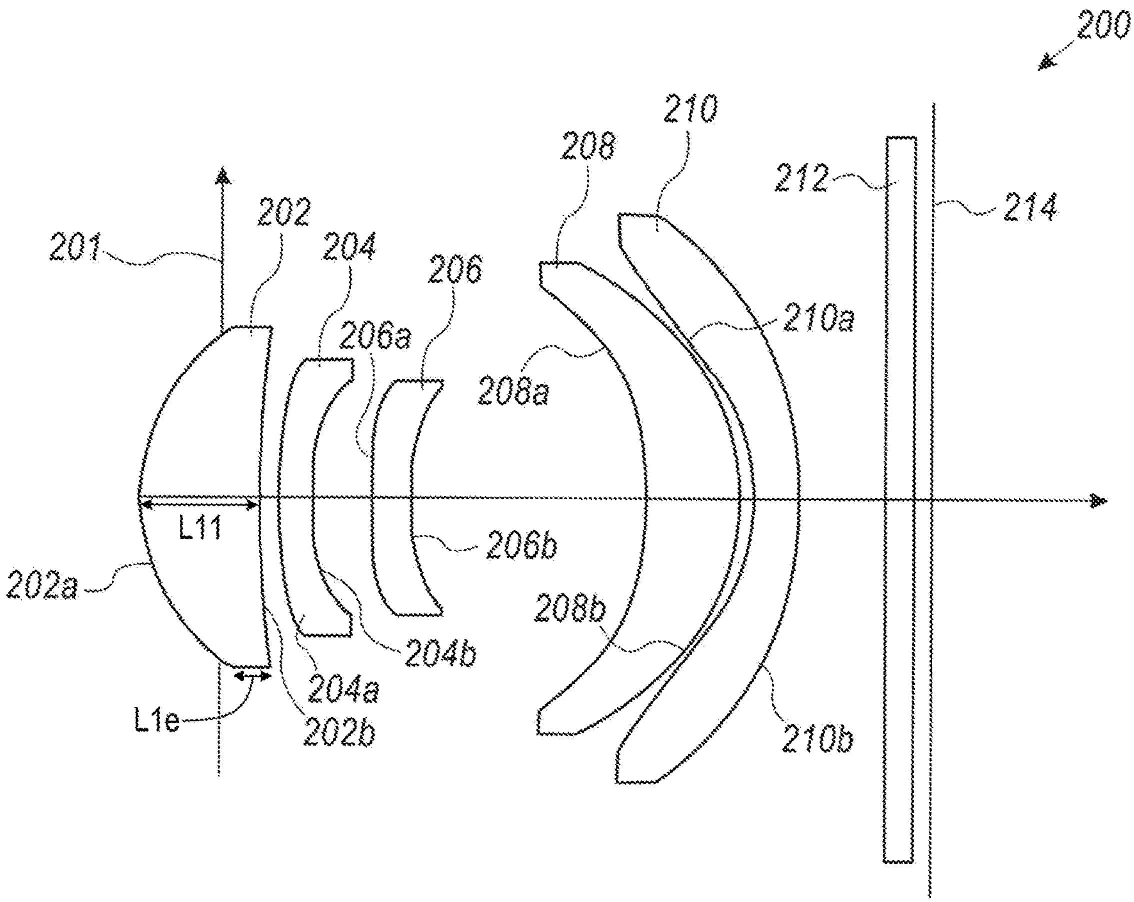
Polychromatic Diffraction Through Focus MTF
Angle 6/2/2013
Data for 0.4350 to 0.6560 µm.
Spatial Frequency: 180.0000 cycles/mm.

FIG. 1B



30/06/2013
Maximum distortion = 1.3%

FIG. 1C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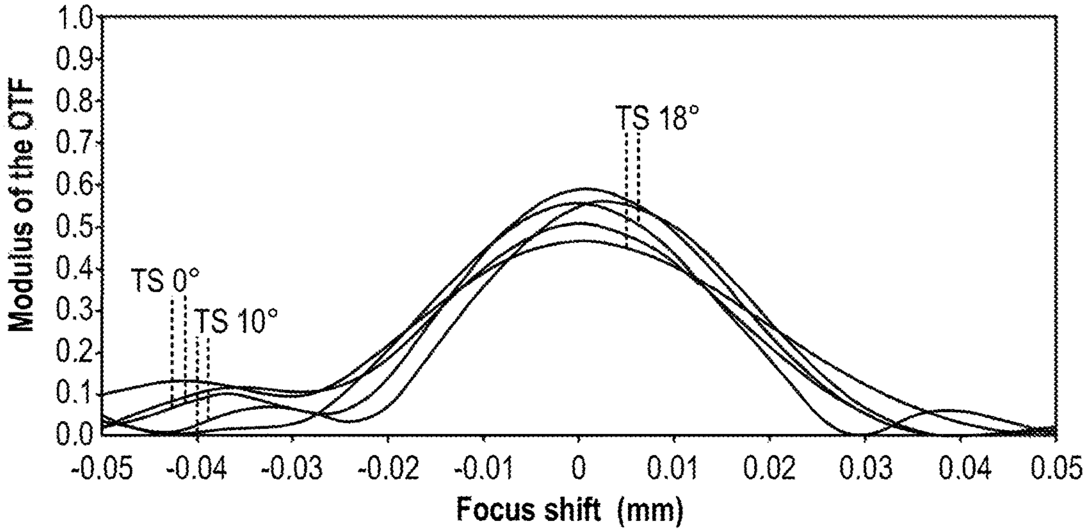
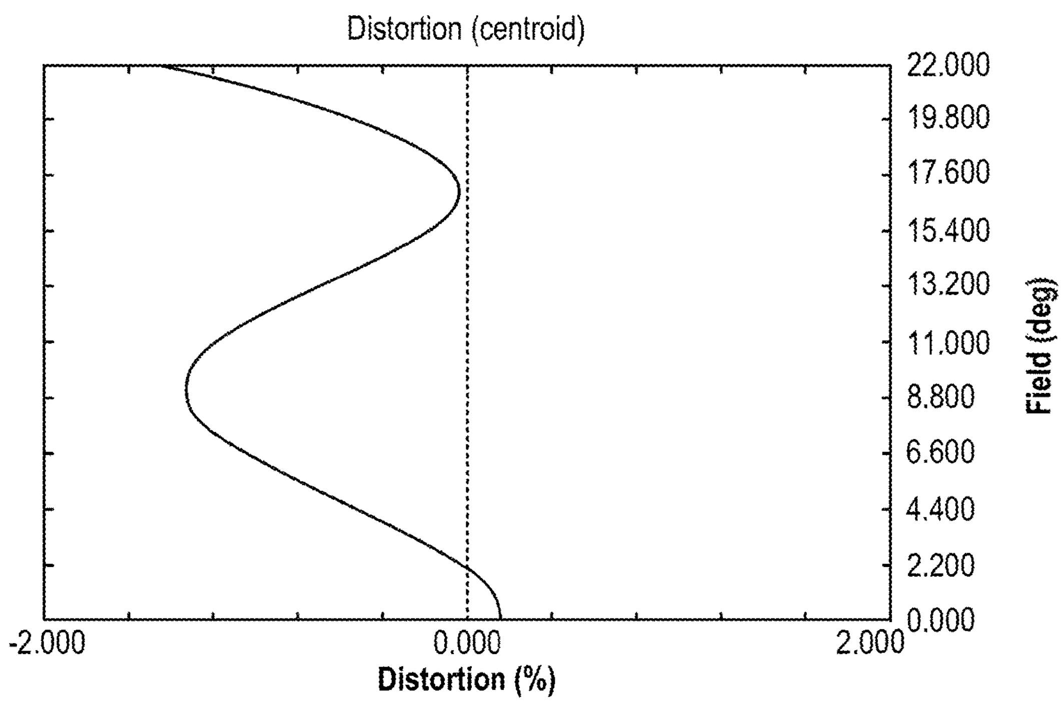
210
208
212
214
201
202
204
206
206a
210a
208a
L11
206b
202a
208b
204b
204a
L1e
202b
210b

FIG. 2A



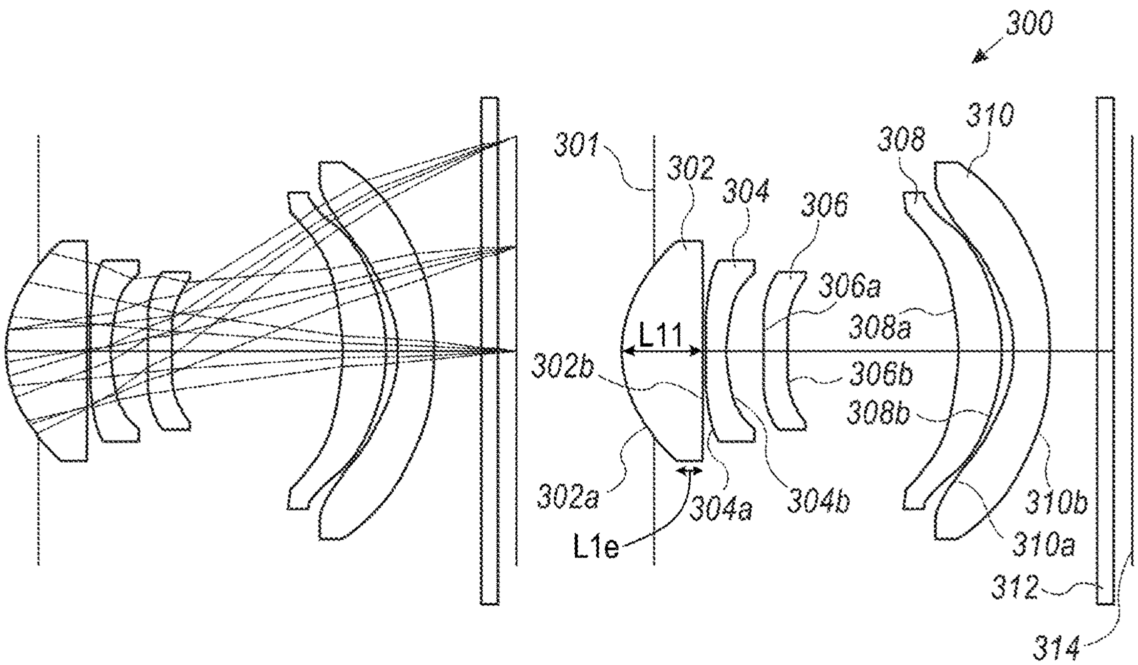
Polychromatic Diffraction Through Focus MTF
Angle 6/2/2013
Data for 0.4350 to 0.6560 μm.
Spatial Frequency: 180.0000 cycles/mm.

FIG. 2B



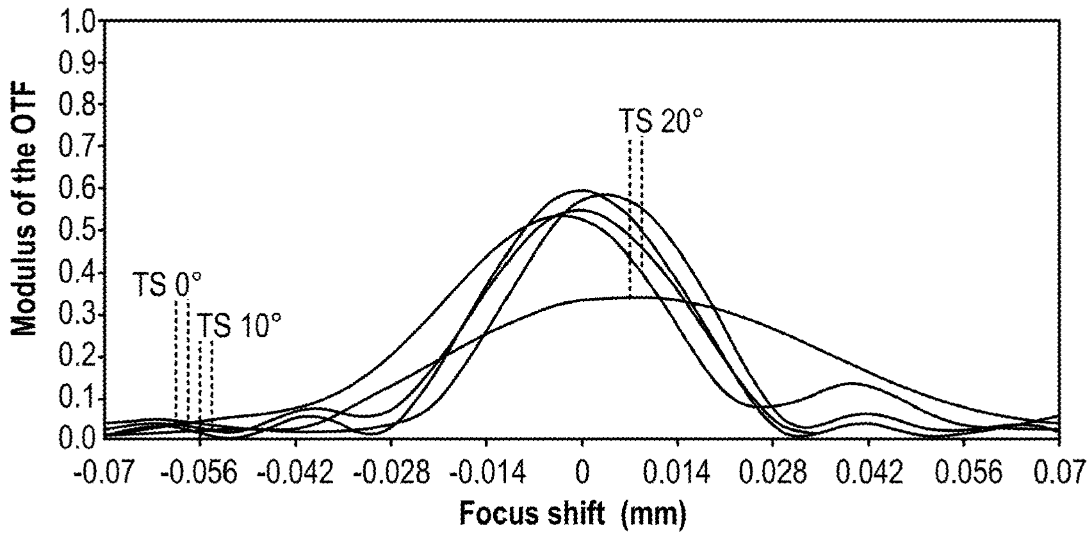
30/06/2013
Maximum distortion = 1.5%

FIG. 2C



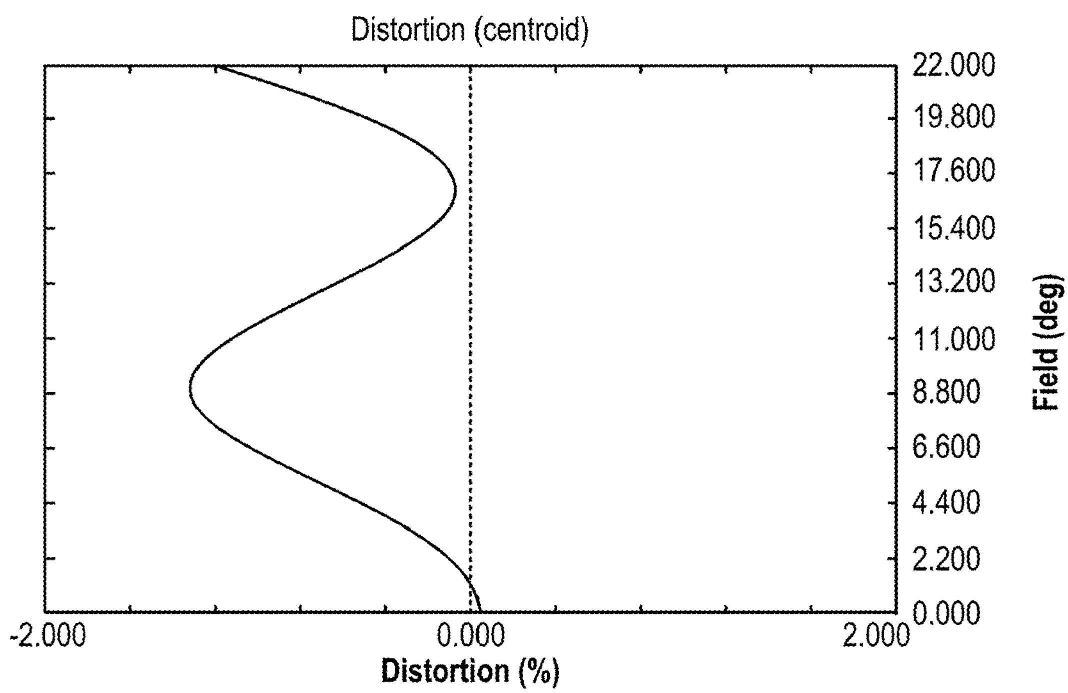
300
301
302
304
306
308
310
306a
308a
L11
302b
306b
308b
302a
304a
304b
310b
310a
L1e
312
314

FIG. 3A



Polychromatic Diffraction Through Focus MTF
Angle 6/9/2013
Data for 0.4350 to 0.6560 µm.
Spatial Frequency: 180.0000 cycles/mm.

FIG. 3B



30/06/2013
Maximum distortion = 1.3%

FIG. 3C

MINIATURE TELEPHOTO LENS ASSEMBLY

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Continuation application of U.S. patent application Ser. No. 15/817,235 filed Nov. 19, 2017, which was a Continuation application of U.S. patent application Ser. No. 15/418,925 filed Jan. 30, 2017, now U.S. Pat. No. 9,857,568, which was a Continuation in Part application of U.S. patent application Ser. No. 15/170,472 filed Jun. 1, 2016, now U.S. Pat. No. 9,568,712, which was a Continuation application of U.S. patent application Ser. No. 14/932,319 filed Nov. 4, 2015, now U.S. Pat. No. 9,402,032, which was a Continuation application of U.S. patent application Ser. No. 14/367,924 filed Jun. 22, 2014, now abandoned, which was a 371 Continuation application of international application PCT/IB2014/062465 filed Jun. 20, 2014, and is related to and claims priority from U.S. Provisional Patent Application No. 61/842,987 filed Jul. 4, 2013, which is incorporated herein by reference in its entirety.

FIELD

Embodiments disclosed herein relate to an optical lens system and lens assembly, and more particularly, to a miniature telephoto lens assembly included in such a system and used in a portable electronic product such as a cellphone.

BACKGROUND

Digital camera modules are currently being incorporated into a variety of host devices. Such host devices include cellular telephones, personal data assistants (PDAs), computers, and so forth. Consumer demand for digital camera modules in host devices continues to grow. Cameras in cellphone devices in particular require a compact imaging lens system for good quality imaging and with a small total track length (TTL). Conventional lens assemblies comprising four lens elements are no longer sufficient for good quality imaging in such devices. The latest lens assembly designs, e.g. as in U.S. Pat. No. 8,395,851, use five lens elements. However, the design in U.S. Pat. No. 8,395,851 suffers from at least the fact that the TTL/EFL (effective focal length) ratio is too large.

Therefore, a need exists in the art for a five lens element optical lens assembly that can provide a small TTL/EFL ratio and better image quality than existing lens assemblies.

SUMMARY

Embodiments disclosed herein refer to an optical lens assembly comprising, in order from an object side to an image side: a first lens element with positive refractive power having a convex object-side surface, a second lens element with negative refractive power having a thickness d_2 on an optical axis and separated from the first lens element by a first air gap, a third lens element with negative refractive power and separated from the second lens element by a second air gap, a fourth lens element having a positive refractive power and separated from the third lens element by a third air gap, and a fifth lens element having a negative refractive power, separated from the fourth lens element by a fourth air gap, the fifth lens element having a thickness d_5 on the optical axis.

An optical lens system incorporating the lens assembly may further include a stop positioned before the first lens element, a glass window disposed between the image-side surface of the fifth lens element and an image sensor with an image plane on which an image of the object is formed.

The effective focal length of the lens assembly is marked "EFL" and the total track length on an optical axis between the object-side surface of the first lens element and the electronic sensor is marked "TTL". In all embodiments, TTL is smaller than the EFL, i.e. the TTL/EFL ratio is smaller than 1.0. In some embodiments, the TTL/EFL ratio is smaller than 0.9. In an embodiment, the TTL/EFL ratio is about 0.85. In all embodiments, the lens assembly has an F number F#<3.2. In an embodiment, the focal length of the first lens element f1 is smaller than TTL/2, the first, third and fifth lens elements have each an Abbe number ("Vd") greater than 50, the second and fourth lens elements have each an Abbe number smaller than 30, the first air gap is smaller than $d_2/2$, the third air gap is greater than TTL/5 and the fourth air gap is smaller than $1.5d_5$. In some embodiments, the surfaces of the lens elements may be aspheric.

In an optical lens assembly disclosed herein, the first lens element with positive refractive power allows the TTL of the lens system to be favorably reduced. The combined design of the first, second and third lens elements plus the relative short distances between them enable a long EFL and a short TTL. The same combination, together with the high dispersion (low Vd) for the second lens element and low dispersion (high Vd) for the first and third lens elements, also helps to reduce chromatic aberration. In particular, the ratio TTL/EFL<1.0 and minimal chromatic aberration are obtained by fulfilling the relationship $1.2\times|f3|>|f2|>1.5\times f1$, where "f" indicates the lens element effective focal length and the numerals 1, 2, 3, 4, 5 indicate the lens element number.

The conditions TTL/EFL<1.0 and F#<3.2 can lead to a large ratio L**11**/L**1***e* (e.g. larger than 4) between the largest width (thickness) L**11** and the smallest width (thickness) of the first lens element (facing the object) L**1***e*. The largest width is along the optical axis and the smallest width is of a flat circumferential edge of the lens element. L**11** and L**1***e* are shown in each of elements **102**, **202** and **302**. A large L**11**/L**1***e* ratio (e.g. >4) impacts negatively the manufacturability of the lens and its quality. Advantageously, the present inventors have succeeded in designing the first lens element to have a L**11**/L**1***e* ratio smaller than 4, smaller than 3.5, smaller than 3.2, smaller than 3.1 (respectively 3.01 for element **102** and 3.08 for element **302**) and even smaller than 3.0 (2.916 for element **202**). The significant reduction in the L**11**/L**1***e* ratio improves the manufacturability and increases the quality of lens assemblies disclosed herein.

The relatively large distance between the third and the fourth lens elements plus the combined design of the fourth and fifth lens elements assist in bringing all fields' focal points to the image plane. Also, because the fourth and fifth lens elements have different dispersions and have respectively positive and negative power, they help in minimizing chromatic aberration.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A shows a first embodiment of an optical lens system disclosed herein;

FIG. **1**B shows the modulus of the optical transfer function (MTF) vs. focus shift of the entire optical lens assembly for various fields in the first embodiment;

FIG. **1**C shows the distortion vs. field angle (+Y direction) in percent in the first embodiment;

FIG. **2**A shows a second embodiment of an optical lens system disclosed herein;

FIG. **2**B shows the MTF vs. focus shift of the entire optical lens assembly for various fields in the second embodiment;

FIG. **2**C shows the distortion +y in percent in the second embodiment;

FIG. **3**A shows a third embodiment of an optical lens system disclosed herein;

FIG. **3**B shows the MTF vs. focus shift of the entire optical lens system for various fields in the third embodiment;

FIG. **3**C shows the distortion +Y in percent in the third embodiment.

DETAILED DESCRIPTION

In the following description, the shape (convex or concave) of a lens element surface is defined as viewed from the respective side (i.e. from an object side or from an image side). FIG. **1**A shows a first embodiment of an optical lens system disclosed herein and marked **100**. FIG. **1**B shows the MTF vs. focus shift of the entire optical lens system for various fields in embodiment **100**. FIG. **1**C shows the distortion +Y in percent vs. field. Embodiment **100** comprises in order from an object side to an image side: an optional stop **101**; a first plastic lens element **102** with positive refractive power having a convex object-side surface **102***a* and a convex or concave image-side surface **102***b*; a second plastic lens element **104** with negative refractive power and having a meniscus convex object-side surface **104***a*, with an image side surface marked **104***b*; a third plastic lens element **106** with negative refractive power having a concave object-side surface **106***a* with an inflection point and a concave image-side surface **106***b*; a fourth plastic lens element **108** with positive refractive power having a positive meniscus, with a concave object-side surface marked **108***a* and an image-side surface marked **108***b*; and a fifth plastic lens element **110** with negative refractive power having a negative meniscus, with a concave object-side surface marked **110***a* and an image-side surface marked **110***b*. The optical lens system further comprises an optional glass window **112** disposed between the image-side surface **110***b* of fifth lens element **110** and an image plane **114** for image formation of an object. Moreover, an image sensor (not shown) is disposed at image plane **114** for the image formation.

In embodiment **100**, all lens element surfaces are aspheric. Detailed optical data is given in Table 1, and the aspheric surface data is given in Table 2, wherein the units of the radius of curvature (R), lens element thickness and/or distances between elements along the optical axis and diameter are expressed in mm. "Nd" is the refraction index. The equation of the aspheric surface profiles is expressed by:

$$z = \frac{cr^2}{1 + \sqrt{1 - (1 + k)c^2 r^2}} + \alpha_1 r^2 + \alpha_2 r^4 + \alpha_3 r^6 + \alpha_4 r^8 + \alpha_5 r^{10} + \alpha_6 r^{12} + \alpha_7 r^{14}$$

where r is distance from (and perpendicular to) the optical axis, k is the conic coefficient, c=1/R where R is the radius of curvature, and a are coefficients given in Table 2 In the equation above as applied to embodiments of a lens assembly disclosed herein, coefficients α_1 and α_7 are zero. Note that the maximum value of r "max r"=Diameter/2. Also note that Table 1 (and in Tables 3 and 5 below), the distances between various elements (and/or surfaces) are marked "Lmn" (where m refers to the lens element number, n=1 refers to the element thickness and n=2 refers to the air gap to the next element) and are measured on the optical axis z, wherein the stop is at z=0. Each number is measured from the previous surface. Thus, the first distance −0.466 mm is measured from the stop to surface **102***a*, the distance L**11** from surface **102***a* to surface **102***b* (i.e. the thickness of first lens element **102**) is 0.894 mm, the gap L**12** between surfaces **102***b* and **104***a* is 0.020 mm, the distance L**21** between surfaces **104***a* and **104***b* (i.e. thickness d**2** of second lens element **104**) is 0.246 mm, etc. Also, L**21**=d_2 and L**51**=d_5. L**11** for lens element **102** is indicated in FIG. **1**A. Also indicated in FIG. **1**A is a width L**1***e* of a flat circumferential edge (or surface) of lens element **102**. L**11** and L**1***e* are also indicated for each of first lens elements **202** and **302** in, respectively, embodiments **200** (FIG. **2**A) and **300** (FIG. **3**A).

TABLE 1

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	−0.466		2.4
2	L11	1.5800	0.894	1.5345/57.095	2.5
3	L12	−11.2003	0.020		2.4
4	L21	33.8670	0.246	1.63549/23.91	2.2
5	L22	3.2281	0.449		1.9
6	L31	−12.2843	0.290	1.5345/57.095	1.9
7	L32	7.7138	2.020		1.8
8	L41	−2.3755	0.597	1.63549/23.91	3.3
9	L42	−1.8801	0.068		3.6
10	L51	−1.8100	0.293	1.5345/57.095	3.9
11	L52	−5.2768	0.617		4.3
12	Window	Infinite	0.210	1.5168/64.17	3.0
13		Infinite	0.200		3.0

TABLE 2

#	Conic coefficient k	α_2	α_3	α_4	α_5	α_6
2	−0.4668	7.9218E−03	2.3146E−02	−3.3436E−02	2.3650E−02	−9.2437E−03
3	−9.8525	2.0102E−02	2.0647E−04	7.4394E−03	−1.7529E−02	4.5206E−03
4	10.7569	−1.9248E−03	8.6003E−02	1.1676E−02	−4.0607E−02	1.3545E−02
5	1.4395	5.1029E−03	2.4578E−01	−1.7734E−01	2.9848E−01	−1.3320E−01
6	0.0000	2.1629E−01	4.0134E−02	1.3615E−02	2.5914E−03	−1.2292E−02
7	−9.8953	2.3297E−01	8.2917E−02	−1.2725E−01	1.5691E−01	−5.9624E−02
8	0.9938	−1.3522E−02	−7.0395E−03	1.4569E−02	−1.5336E−02	4.3707E−03
9	−6.8097	−1.0654E−01	1.2933E−02	2.9548E−04	−1.8317E−03	5.0111E−04
10	−7.3161	−1.8636E−01	8.3105E−02	−1.8632E−02	2.4012E−03	−1.2816E−04
11	0.0000	−1.1927E−01	7.0245E−02	−2.0735E−02	2.6418E−03	−1.1576E−04

Embodiment **100** provides a field of view (FOV) of 44 degrees, with EFL=6.90 mm, F#=2.80 and TTL of 5.904 mm. Thus and advantageously, the ratio TTL/EFL=0.855. Advantageously, the Abbe number of the first, third and fifth lens element is 57.095. Advantageously, the first air gap between lens elements **102** and **104** (the gap between surfaces **102***b* and **104***a*) has a thickness (0.020 mm) which is less than a tenth of thickness d_2 (0.246 mm). Advantageously, the Abbe number of the second and fourth lens elements is 23.91. Advantageously, the third air gap between lens elements **106** and **108** has a thickness (2.020 mm) greater than TTL/5 (5.904/5 mm). Advantageously, the fourth air gap between lens elements **108** and **110** has a thickness (0.068 mm) which is smaller than $1.5d_5$ (0.4395 mm).

The focal length (in mm) of each lens element in embodiment **100** is as follows: f1=2.645, f2=−5.578, f3=−8.784, f4=9.550 and f5=−5.290. The condition $1.2\times|f3|>|f2|<1.5\times f1$ is clearly satisfied, as 1.2×8.787>5.578>1.5×2.645. f1 also fulfills the condition $f1<TTL/2$, as 2.645<2.952.

Using the data from row #2 in Tables 1 and 2, L**1***e* in lens element **102** equals 0.297 mm, yielding a center-to-edge thickness ratio L**11**/L**1***e* of 3.01.

FIG. **2**A shows a second embodiment of an optical lens system disclosed herein and marked **200**. FIG. **2**B shows the MTF vs. focus shift of the entire optical lens system for various fields in embodiment **200**. FIG. **2**C shows the distortion +Y in percent vs. field. Embodiment **200** comprises in order from an object side to an image side: an optional stop **201**; a first plastic lens element **202** with positive refractive power having a convex object-side surface **202***a* and a convex or concave image-side surface **202***b*; a second glass lens element **204** with negative refractive power, having a meniscus convex object-side surface **204***a*, with an image side surface marked **204***b*; a third plastic lens element **206** with negative refractive power having a concave object-side surface **206***a* with an inflection point and a concave image-side surface **206***b*; a fourth plastic lens element **208** with positive refractive power having a positive meniscus, with a concave object-side surface marked **208***a* and an image-side surface marked **208***b*; and a fifth plastic lens element **210** with negative refractive power having a negative meniscus, with a concave object-side surface marked **110***a* and an image-side surface marked **210***b*. The optical lens system further comprises an optional glass window **212** disposed between the image-side surface **210***b* of fifth lens element **210** and an image plane **214** for image formation of an object.

In embodiment **200**, all lens element surfaces are aspheric. Detailed optical data is given in Table 3, and the aspheric surface data is given in Table 4, wherein the markings and units are the same as in, respectively, Tables 1 and 2. The equation of the aspheric surface profiles is the same as for embodiment **100**.

TABLE 3

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	−0.592		2.5
2	L11	1.5457	0.898	1.53463/56.18	2.6
3	L12	−127.7249	0.129		2.6
4	L21	6.6065	0.251	1.91266/20.65	2.1
5	L22	2.8090	0.443		1.8
6	L31	9.6183	0.293	1.53463/56.18	1.8
7	L32	3.4694	1.766		1.7
8	L41	−2.6432	0.696	1.632445/23.35	3.2
9	L42	−1.8663	0.106		3.6
10	L51	−1.4933	0.330	1.53463/56.18	3.9
11	L52	−4.1588	0.649		4.3
12	Window	Infinite	0.210	1.5168/64.17	5.4
13		Infinite	0.130		5.5

TABLE 4

#	Conic coefficient k	α_2	α_3	α_4	α_5	α_6
2	0.0000	−2.7367E−03	2.8779E−04	−4.3661E−03	3.0069E−03	−1.2282E−03
3	−10.0119	4.0790E−02	−1.8379E−02	2.2562E−02	−1.7706E−02	4.9640E−03
4	10.0220	4.6151E−02	5.8320E−02	−2.0919E−02	−1.2846E−02	8.8283E−03
5	7.2902	3.6028E−02	1.1436E−01	−1.9022E−02	4.7992E−03	−3.4079E−03
6	0.0000	1.6639E−01	5.6754E−02	−1.2238E−02	−1.8648E−02	1.9292E−02
7	8.1261	1.5353E−01	8.1427E−02	−1.5773E−01	1.5303E−01	−4.6064E−02
8	0.0000	−3.2628E−02	1.9535E−02	−1.6716E−02	−2.0132E−03	2.0112E−03
9	0.0000	1.5173E−02	−1.2252E−02	3.3611E−03	−2.5303E−03	8.4038E−04
10	−4.7688	−1.4736E−01	7.6335E−02	−2.5539E−02	5.5897E−03	−5.0290E−04
11	0.00E+00	−8.3741E−02	4.2660E−02	−8.4866E−03	1.2183E−04	7.2785E−05

Embodiment **200** provides a FOV of 43.48 degrees, with EFL=7 mm, F#=2.86 and TTL=5.90 mm. Thus and advantageously, the ratio TTL/EFL=0.843. Advantageously, the Abbe number of the first, third and fifth lens elements is 56.18. The first air gap between lens elements **202** and **204** has a thickness (0.129 mm) which is about half the thickness d_2 (0.251 mm). Advantageously, the Abbe number of the second lens element is 20.65 and of the fourth lens element is 23.35. Advantageously, the third air gap between lens elements **206** and **208** has a thickness (1.766 mm) greater than TTL/5 (5.904/5 mm). Advantageously, the fourth air gap between lens elements **208** and **210** has a thickness (0.106 mm) which is less than $1.5\times d_5$ (0.495 mm).

The focal length (in mm) of each lens element in embodiment **200** is as follows: f1=2.851, f2=−5.468, f3=−10.279, f4=7.368 and f5=−4.536. The condition $1.2\times|f3|>|f2|<1.5\times f1$ is clearly satisfied, as 1.2×10.279>5.468>1.5×2.851. f1 also fulfills the condition $f1<TTL/2$, as 2.851<2.950.

Using the data from row #2 in Tables 3 and 4, L**1***e* in lens element **202** equals 0.308 mm, yielding a center-to-edge thickness ratio L**11**/L**1***e* of 2.916.

FIG. **3**A shows a third embodiment of an optical lens system disclosed herein and marked **300**. FIG. **3**B shows the MTF vs. focus shift of the entire optical lens system for various fields in embodiment **300**. FIG. **3**C shows the distortion +Y in percent vs. field. Embodiment **300** com-

prises in order from an object side to an image side: an optional stop **301**; a first glass lens element **302** with positive refractive power having a convex object-side surface **302***a* and a convex or concave image-side surface **302***b*; a second plastic lens element **204** with negative refractive power, having a meniscus convex object-side surface **304***a*, with an image side surface marked **304***b*; a third plastic lens element **306** with negative refractive power having a concave object-side surface **306***a* with an inflection point and a concave image-side surface **306***b*; a fourth plastic lens element **308** with positive refractive power having a positive meniscus, with a concave object-side surface marked **308***a* and an image-side surface marked **308***b*; and a fifth plastic lens element **310** with negative refractive power having a negative meniscus, with a concave object-side surface marked **310***a* and an image-side surface marked **310***b*. The optical lens system further comprises an optional glass window **312** disposed between the image-side surface **310***b* of fifth lens element **310** and an image plane **314** for image formation of an object.

In embodiment **300**, all lens element surfaces are aspheric. Detailed optical data is given in Table 5, and the aspheric surface data is given in Table 6, wherein the markings and units are the same as in, respectively, Tables 1 and 2. The equation of the aspheric surface profiles is the same as for embodiments **100** and **200**.

TABLE 5

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	−0.38		2.4
2	L11	1.5127	0.919	1.5148/63.1	2.5
3	L12	−13.3831	0.029		2.3
4	L21	8.4411	0.254	1.63549/23.91	2.1
5	L22	2.6181	0.426		1.8
6	L31	−17.9618	0.265	1.5345/57.09	1.8
7	L32	4.5841	1.998		1.7
8	L41	−2.8827	0.514	1.63549/23.91	3.4
9	L42	−1.9771	0.121		3.7
10	L51	−1.8665	0.431	1.5345/57.09	4.0
11	L52	−6.3670	0.538		4.4
12	Window	Infinite	0.210	1.5168/64.17	3.0
13		Infinite	0.200		3.0

TABLE 6

#	Conic coefficient k	α_2	α_3	α_4	α_5	α_6
2	−0.534	1.3253E−02	2.3699E−02	−2.8501E−02	1.7853E−02	−4.0314E−03
3	−13.473	3.0077E−02	4.7972E−03	1.4475E−02	−1.8490E−02	4.3565E−03
4	−10.132	7.0372E−04	1.1328E−01	1.2346E−03	−4.2655E−02	8.8625E−03
5	5.180	−1.9210E−03	2.3799E−01	−8.8055E−02	2.1447E−01	−1.2702E−01
6	0.000	2.6780E−01	1.8129E−02	−1.7323E−02	3.7372E−02	−2.1356E−02
7	10.037	2.7660E−01	−1.0291E−02	−6.0955E−02	7.5235E−02	−1.6521E−02
8	1.703	2.6462E−02	−1.2633E−02	−4.7724E−04	−3.2762E−03	1.6551E−03
9	−1.456	5.7704E−03	−1.8826E−02	5.1593E−03	−2.9999E−03	8.0685E−04
10	−6.511	−2.1699E−01	1.3692E−01	−4.2629E−02	6.8371E−03	−4.1415E−04
11	0.000	−1.5120E−01	8.6614E−02	−2.3324E−02	2.7361E−03	−1.1236E−04

Embodiment **300** provides a FOV of 44 degrees, EFL=6.84 mm, F#=2.80 and TTL=5.904 mm. Thus and advantageously, the ratio TTL/EFL=0.863. Advantageously, the Abbe number of the first lens element is 63.1, and of the third and fifth lens elements is 57.09. The first air gap between lens elements **302** and **304** has a thickness (0.029 mm) which is about $1/10^{th}$ the thickness d_2 (0.254 mm). Advantageously, the Abbe number of the second and fourth lens elements is 23.91. Advantageously, the third air gap between lens elements **306** and **308** has a thickness (1.998 mm) greater than TTL/5 (5.904/5 mm). Advantageously, the fourth air gap between lens elements **208** and **210** has a thickness (0.121 mm) which is less than $1.5d_5$ (0.6465 mm).

The focal length (in mm) of each lens element in embodiment **300** is as follows: f1=2.687, f2=−6.016, f3=−6.777, f4=8.026 and f5=−5.090. The condition 1.2×|f3|>|f2|<1.5×f1 is clearly satisfied, as 1.2×6.777>6.016>1.5×2.687. f1 also fulfills the condition f1<TTL/2, as 2.687<2.952.

Using the data from row #2 in Tables 5 and 6, L**1***e* in lens element **302** equals 0.298 mm, yielding a center-to-edge thickness ratio L**11**/L**1***e* of 3.08.

While this disclosure has been described in terms of certain embodiments and generally associated methods, alterations and permutations of the embodiments and methods will be apparent to those skilled in the art. The disclosure is to be understood as not limited by the specific embodiments described herein, but only by the scope of the appended claims.

What is claimed is:

1. A lens assembly, comprising: a plurality of lens elements arranged along an optical axis and spaced apart by respective spaces, wherein the lens assembly has an effective focal length (EFL), a total track length (TTL) of 6.5 millimeters or less and a ratio TTL/EFL<1.0, wherein the plurality of lens elements includes, in order from an object side to an image side, a first group comprising lens elements L_{1_1}, L_{1_2} and L_{1_3} with respective focal lengths f_{1_1}, f_{1_2} and f_{1_3} and a second group comprising lens elements L_{2_1} and L_{2_2}, wherein the first and second groups of lens elements are separated by a gap that is larger than twice any other gap between lens elements, wherein lens element L_{1_1} has positive refractive power and lens element L_{1_2} has negative refractive power and wherein lens elements L_{2_1} and L_{2_2} have opposite refractive powers.

2. The lens assembly of claim **1**, wherein the TTL is equal or smaller than 6.0 mm and wherein the lens assembly has a f-number F#<2.9.

3. The lens assembly of claim **1**, wherein the TTL is equal or smaller than 6.0 mm and wherein lens element L_{1_1} has an image-side surface diameter between 2.3 mm and 2.5 mm.

4. The lens assembly of claim **1**, wherein f_{1_1}<TTL/2.

5. The lens assembly of claim **1**, wherein the lens assembly has a f-number F#<2.9.

6. The lens assembly of claim **5**, wherein lens element L_{1_1} has a concave image-side surface.

7. The lens assembly of claim **1**, wherein the lens assembly has a f-number F#=2.

8. The lens assembly of claim **5**, wherein lens element L_{1_1} has a convex image-side surface.

9. The lens assembly of claim **1**, wherein $1.2\times|f_{1\_3}|>1.5\times f_{1\_1}$.

10. The lens assembly of claim **1**, wherein $1.2\times|f_{1\_3}|>|f_{1\_2}|>1.5\times f_{1\_1}$.

11. The lens assembly of claim **1**, wherein a combined power of lens elements L_{1_2} and L_{1_3} is negative.

12. The lens assembly of claim **1**, wherein L_{1_3} has negative refractive power.

13. The lens assembly of claim **1**, wherein the gap between lens elements L_{2_1} and L_{2_2} is smaller than $1.5\times d_{2\_2}$, where d_{2_2} is a thickness of lens element L_{2_2} along the optical axis.

14. The lens assembly of claim **1**, wherein lens elements L_{2_1} and L_{2_2} are separated by a gap smaller than TTL/20.

15. The lens assembly of claim **1**, wherein L_{2_1} and L_{2_2} are made of different lens materials having different Abbe numbers, such that one lens element has Abbe number that is smaller than 30 and the other lens element has an Abbe number that is larger than 50.

16. The lens assembly of claim **2**, wherein the lens assembly further includes a ratio between a largest optical axis thickness L**11** and a circumferential edge thickness Lle of lens element L_{11} of L**11**/L**1***e*<3.

17. A lens assembly, comprising a plurality of lens elements arranged along an optical axis and spaced apart by respective spaces, wherein the lens assembly has an effective focal length (EFL), wherein a lens system that includes the lens assembly plus a window positioned between the plurality of lens elements and an image plane has a total track length (TTL) of 6.5 millimeters or less, wherein a ratio TTL/EFL <1.0, wherein the plurality of lens elements includes, in order from an object side to an image side, a first group comprising lens elements L_{1_1}, L_{1_2} and L_{1_3} with respective focal lengths f_{1_2} and f_{1_3}, and a second group comprising lens elements L_{2_1} and L_{2_2}, wherein lens element L_{1_1} has positive refractive power and lens element

L_{1_2} has negative refractive power, wherein $1.2\times|f_{1\_3}|>|f_{1\_2}|>1.5\times f_{1\_1}$ and wherein lens elements L_{2_1} and L_{2_2} have opposite refractive powers.

18. The lens assembly of claim **17**, wherein the TTL is equal or smaller than 6.0 mm and wherein the lens assembly has a f-number F#<2.9.

19. The lens assembly of claim **17**, wherein the TTL is equal or smaller than 6.0 mm and wherein lens element L_{1_1} has an image-side surface diameter between 2.3 mm and 2.5 mm.

20. The lens assembly of claim **17**, wherein f_{1_1}<TTL/2.

21. The lens assembly of claim **17**, wherein the lens assembly has a f-number F#<2.9.

22. The lens assembly of claim **21**, wherein lens element L_{1_1} has a concave image-side surface.

23. The lens assembly of claim **17**, wherein the lens assembly has a f-number F#=2.8.

24. The lens assembly of claim **21**, wherein lens element L_{1_1} has a convex image-side surface.

25. The lens assembly of claim **17**, wherein a combined power of lens elements L_{1_2} and L_{1_3} is negative.

26. The lens assembly of claim **17**, wherein L_{1_3} has negative refractive power.

27. The lens assembly of claim **17**, wherein a gap between lens elements L_{2_1} and L_{2_2} is smaller than $1.5\times d_5$, where d_5 is a thickness of lens element L_{2_2} along the optical axis.

28. The lens assembly of claim **17**, wherein lens elements L_{2_1} and L_{2_2}, are separated by a gap smaller than TTL/20.

29. The lens assembly of claim **17**, wherein L_{2_1} and L_{2_2} are made of different lens materials having different Abbe numbers, such that one lens element has an Abbe number that is smaller than 30 and the other lens element has an Abbe number that is larger than 50.

30. The lens assembly of claim **18**, wherein the lens assembly further includes a ratio between a largest optical axis thickness L**11** and a circumferential edge thickness L**1***e* of lens element L_{1_1} of L**11**/L**1***e*<3.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.,
Petitioner,

v.

COREPHOTONICS LTD.,
Patent Owner

U.S. Patent No. 10,330,897

Declaration of José Sasián, Ph.D.
under 37 C.F.R. § 1.68

matter pertains. I have also been informed by counsel that the obviousness analysis takes into account factual inquiries including the level of ordinary skill in the art, the scope and content of the prior art, and the differences between the prior art and the claimed subject matter.

27. I have been informed by counsel that the Supreme Court has recognized several rationales for combining references or modifying a reference to show obviousness of claimed subject matter. Some of these rationales include the following: (a) combining prior art elements according to known methods to yield predictable results; (b) simple substitution of one known element for another to obtain predictable results; (c) use of a known technique to improve a similar device (method, or product) in the same way; (d) applying a known technique to a known device (method, or product) ready for improvement to yield predictable results; (e) choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success; and (f) some teaching, suggestion, or motivation in the prior art that would have led one of ordinary skill to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention.

V. OVERVIEW OF THE ’897 PATENT

A. Summary of the Patent

28. The ’897 Patent is directed to “[a]n optical lens assembly [that] includes five lens elements and provides a TTL/EFL<1.0.” APPL-1001, Abstract. A ratio of total track length (“TTL”) over effective focal length (“EFL”) being less than one is indicative of a telephoto lens system. *See* APPL-1006, p.169. As admitted by the Applicant in the ’897 Patent, it was and still is common to incorporate digital cameras into a variety of devices including cellular telephones, personal digital assistants, and other portable electronic devices. *See* APPL-1001, 1:34-38. The driving need for cameras in such devices is a growing consumer demand for portable cameras with “good quality imaging and … a small total track length.” *See id.*, 1:38-42.

29. According to the Applicant, the lens system in the ’897 Patent is allegedly the answer to the known need for good quality imaging and a small total track length. *See id.*, 1:43-50. The lens system in the ’897 Patent includes:

> a first lens element with positive refractive power having a convex object-side Surface, a second lens element with negative refractive power having a thickness d_2 on an optical axis and separated from the first lens element by a first air gap, a third lens element with negative refractive power and separated from the second lens element by a second air gap, a fourth lens element having a positive refractive power and separated from the third lens element by a third air gap, and a fifth lens element having a negative refractive power, separated from the

which notes that edge thickness can be determined using the optical data and aspheric coefficients. *See id.*, 5:21-23 (stating that edge thickness of the first lens element, L1e, can be determined using the optical data and aspheric coefficients for the first lens element).

32. As discussed below, none of these characteristics were new. Prior to July 4, 2013, five element lens assemblies for mobile phones were well known, including telephoto lenses. *See* APPL-1006, pp.169-182; APPL-1005, Fig. 5. For example, Ogino (APPL-1005) teaches a similar five lens system with a TTL to EFL ratio of less than one. In my opinion, the disclosures provided in Ogino and other prior art discussed below either anticipate or render obvious each and every element of the claims I have been asked to analyze in the ’897 Patent, as discussed below.

B. Priority Date of the ’897 Patent

33. I am informed that the ’897 Patent is a continuation of a string of patent applications claiming the benefit of Provisional Application No. 61/842,987 filed on July 4, 2013. See APPL-1001. The subject matter of claims 16 and 30, though, appears to be first added in U.S. Patent No. 9,857,568 filed on January 30, 2017 as a continuation-in-part of U.S. Patent No. 9,568,712. *Compare* APPL-1021 *with* APPL-1022. This would have been apparent to a POSITA since the applications filed prior to the ’568 Patent make no mention of a center thickness

U.S. 10,330,897	Ogino
separated by a gap smaller than TTL/20.	
Claim 29	
[29.0] The lens assembly of claim 17, wherein L_{2_1}, and L_{2_2} are made of different lens materials having different Abbe numbers, such that one lens element has an Abbe number that is smaller than 30 and the other lens element has an Abbe number that is larger than 50.	This limitation is the same as [15.0] and is disclosed for the same reasons discussed above.

B. Claims 2, 5, 6, 18, and 21-23 are obvious over the combination of Ogino and Bareau.

1. Summary of Bareau

47. Bareau refers to "The optics of miniature digital camera modules" by Jane Bareau and Peter P. Clark (APPL-1012). Bareau was originally presented at the International Optical Design Conference in June 2006, for which I was in attendance along with other members of the public. Bareau was also later published in SPIE Proceedings Vol. 6342, for which I received a copy a few months after the conference. My personal knowledge is consistent with the

information on the bottom of page 1 of Bareau, which states that it was both presented and published in 2006. *See* Ex.1012, p.1.

48. Bareau generally discusses how "[d]esigning lenses for cell phone cameras is different from designing for traditional imaging systems." *Id.*, p.1. To this end, Bareau offers a number of "typical lens specifications" for use in cellular telephones, which include an f-number of 2.8 or less so that enough light will be provided to ¼" and smaller sensor formats. *Id.*, pp.3-4 (also indicating that smaller sensors suffer at higher f-numbers due to limited light capturing ability). Bareau also indicates a preference for a TTL of about 5.0 mm due to a desire to make the cell phone thin as well as maintaining relative illumination at the edge of the field of greater than 50 percent. *Id.*, pp.3,7. A POSITA would have understood these to be general specifications with some modifications allowed depending on the specific implementation, sensor, and desired purpose. *See* APPL-1024, 1:30-53

49. Bareau also generally describes the understanding of a POSITA that designing photographic lenses with a low f-number has been and continues to be an important trend in lens design. *See, e.g.*, *id.*, pp.3-4. Bareau therefore serves as evidence that a POSITA would have considered two main driving factors for cell phone lens specifications including a small total track length (TTL) to make the overall cell phone thin and a low f-number to allow enough light to reach the

sensor. *See, e.g.*, *id.*, pp.3-4; APPL-1013, p.104 (indicating a general desire to design "faster" lenses for brighter images).

50. Thus, a POSITA designing lens assemblies for use in a cell phone would have been informed by Bareau to design or modify a lens system that fit within the specifications including maintaining a short track length, an f-number of 2.8 or lower for ¼" and smaller sensor formats, and relative illumination greater than 50 percent.

2. Reasons to combine Ogino and Bareau

51. It is my opinion that a POSITA would have found it obvious to modify Ogino's Example 5 lens assembly in view of Bareau's specifications for cell phone camera lenses with an F#=2.8 or less for ¼" and smaller image sensors. Such a combination would have been nothing more than applying Bareau's specification for a brighter lens system for smaller image sensors, according to known lens design and modification methods (as taught in APPL-1017, p.172), to yield a predictable result of Ogino's Example 5 lens assembly likewise supporting an f-number of 2.8 or lower for a small sensor format. *See id.*, pp.3-4.

52. Bareau was published in 2006. *Id.*, p.1. By 2013 (the priority date of the '897 Patent), cell phones having cameras with an f-number of 2.8 or lower for ¼" and smaller sensors were common and it was at least expected that cell phone camera lenses would satisfy similar specifications. *See id.*, p.3; APPL-1024, 1:39-

42. A POSITA's desire to achieve lens designs with lower f-numbers was also well known and driven by a recognized need for "faster" lenses. *See* APPL-1013, p.104 ("The tremendous efforts of lens designers and manufacturers that have been devoted to the production of lenses of extremely high relative aperture are an indication of **the need that exists for brighter images and 'faster' lenses**."). To have a competitive lens design, a POSITA therefore would have sought to modify existing lens designs to achieve faster f-numbers like 2.8 while still maintaining a short total track length appropriate for thin cell phone designs.

53. A POSITA thus would have been aware of Bareau's specifications for lens assemblies designed for modern cellular telephones and particularly the importance of supporting a faster f-number for smaller sensor formats. Consequently, a POSITA looking to implement a telephoto lens in a cell phone with, for example, a common ¼" sensor format would have been motivated to look to lens designs like Ogino's that could support a lower, more desirable f-number since Ogino's other embodiments support f-number values down to 2.45 as discussed above. Thus, modifying Ogino's Example 5 to have an f-number of 2.8, as taught in Bareau, would have been nothing more than applying Bareau's specification of an F#=2.8 for a ¼" image sensor format according to known lens design methods (as taught in Fischer (APPL-1017)) to allow Example 5 to likewise better support a ¼" sensor format in a thin cell phone.

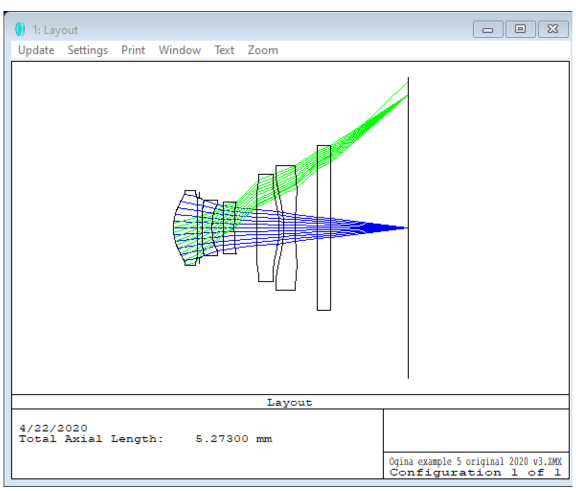
54. While Bareau specifies a field of view (FOV) of 60 degrees, this would have been understood to be a design consideration since most cell phones at the time used a single wide lens. *See, e.g.*, APPL-1005, Figs. 14, 15. A POSITA designing a cell phone with both wide and telephoto lenses using the same sensor format, (*see, e.g.*, APPL-1014, Fig.16), though, would have recognized that Bareau's specifications for f-number and short TTL would still be highly relevant to incorporating a telephoto lens like Example 5 since TTL dictates the thickness of the cell phone and the f-number indicates how much light reaches the image sensor regardless of a lens's focal length or FOV. *See* APPL-1012, pp.3-4. Based on these considerations, a POSITA seeking a telephoto lens with a low f-number would have looked to modify Ogino's Example 5 since Ogino's other examples support lower f-numbers and modifying an existing lens design takes far less time than starting from scratch, and lens designers often start designs using existing examples in the patent literature.

55. A POSITA would have understood that one way of modifying Ogino's Example 5 is to increase the diameter of one or more lens element surfaces, particularly the first lens in Example 5 since this lens serves as the entrance aperture. This is due to the relationship between f-number, focal length (EFL), and the diameter of the entrance aperture (i.e. the entrance pupil diameter EPD) which controls the amount of light that enters the assembly:

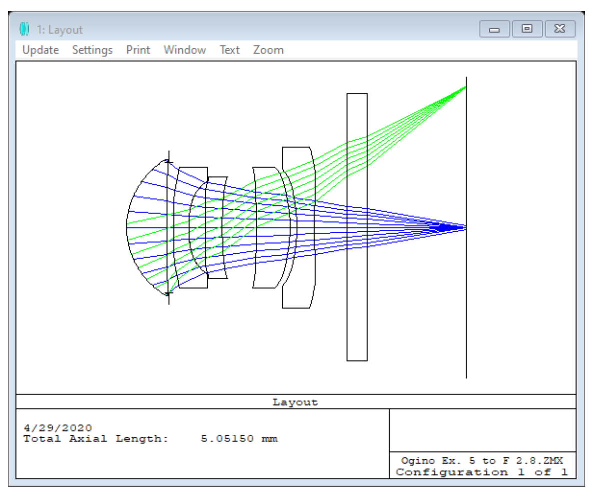
$$f\text{-}number = \frac{EFL}{diameter} = \frac{EFL}{EPD}$$

See APPL-1016, p.59. Given the arrangement of the lenses in Example 5 where the aperture is located behind the first lens L1, a POSITA would have recognized that increasing the diameter of L1's surfaces would thereby also increase the aperture and allow more light to enter the system. *See id.*, p.60, 67-69 (explaining that a change in the entrance pupil or aperture stop leads to a change in the diameter of the lens).

56. Modifying Example 5 to achieve the Bareau's preferred F#=2.8 and using well-known lens design software to find the best solution, a POSITA would have arrived at one possible lens design as shown below:

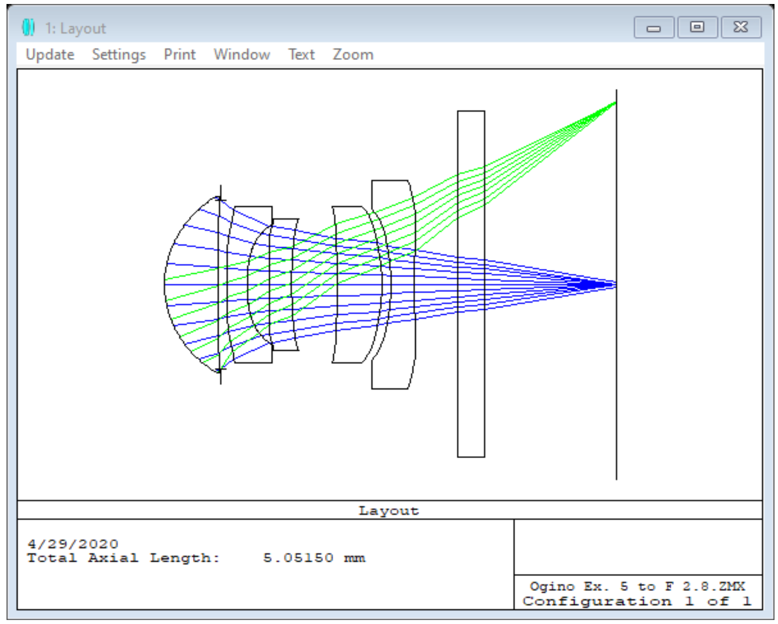


Ogino Example 5 (F#=3.94)



Example 5 modified with F#=2.8

See infra Appendix, Figs. 1A, 2A. In the modified design, EFL=5.648 mm, TTL=5.271 mm, and radii of curvature, spacing, and focal lengths of lens elements

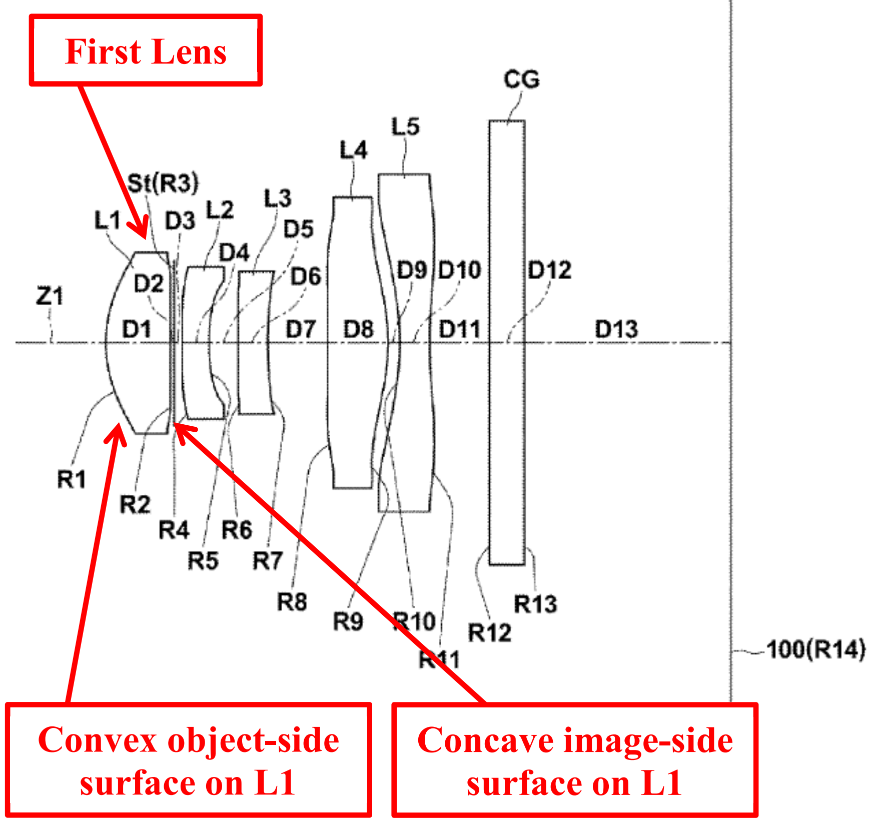
	 *See infra* Appendix. The entrance pupil diameter here is EPD=2.0171 mm and so the F/#=EFL/EPD=2.8. Thus, Ogino's Example 5 modified based on Bareau's teachings to support an F# of 2.8 renders obvious "*wherein the lens assembly has a f-number F# < 2.9*" as recited in the claim.
Claim 5	
[5.0] The lens assembly of claim 1, wherein the lens assembly has a f-number F# < 2.9.	This limitation is the same as [2.1] and is disclosed for the same reasons discussed above.
Claim 6	
[6.0] The lens assembly of claim 5, wherein lens element L_{1_1} has a concave image-side surface.	Ogino discloses this limitation because the L1 lens (i.e., L_{1_1}) in the Example 5 lens assembly has a convex object-side surface and a concave image-side surface: As in the first embodiment, the imaging lenses according to the second to **<u>sixth embodiments</u>** of the present invention substantially consist of, in order from the

> object side, five lenses of: **<u>the first lens L1</u>** that has a positive refractive power and **<u>has a meniscus shape which is convex toward the object side</u>**; the second lens L2 that has a biconcave shape.

APPL-1005, 13:5-11.

This is also shown in Fig. 5, below:

FIG.5 EXAMPLE 5



APPL-1005, Fig. 5 (annotated).

A POSITA would have recognized that the description of the first lens L1 as having "a meniscus shape which is convex toward the object side" means that the first lens has a convex object-side surface and a concave image-side surface. This is because meniscus lenses are commonly known to include one convex side and one concave side. For example, Born (APPL-1010) describes a number of lens types including meniscus lenses in Fig. 4.15 below:

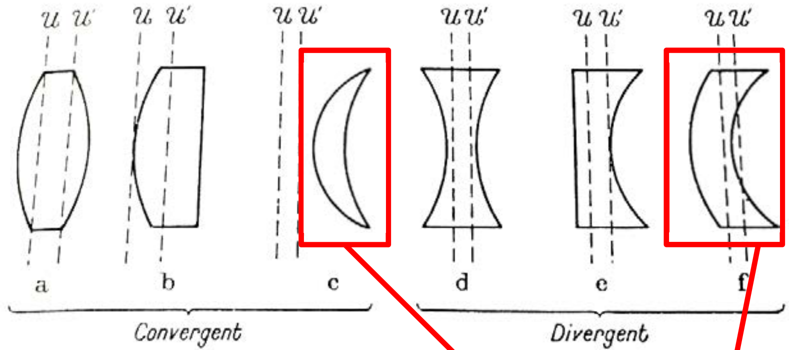


Fig. 4.15. Common types of lenses:
(a) Double-convex; (b) Plano-convex; (c) Convergent meniscus;
(d) Double-concave; (e) Plano-concave; (f) Divergent meniscus.

APPL-1010, Fig. 4.15 (annotated).

As shown in Born's Fig. 4.15, lens (c) is labeled "Convergent meniscus" and lens (f) is labeled "Divergent meniscus." Both lenses include a **convex surface** and a **concave surface** as shown in comparison to the other lenses shown in Fig. 4.15 (compare with e.g., lens (a) labeled "Double convex" and lens (d) labeled "Double concave"). APPL-1010, Fig. 4.15. Accordingly, a POSITA would have understood that the description of Ogino's first lens L1 in Example 5 as having "a meniscus shape which is convex toward the object side," means that the other side—the image side—is concave. In other words, that Ogino's first lens L1 in Example 5 has a convex object-side surface and a concave image-side surface.

The radius of curvatures provided for lens L1 in Table 9 further show that the first lens element has a convex object-side surface and a concave image-side surface. Specifically, the radius of curvatures rd is measured from the object side. Thus, a positive rd of 1.12444 for the object-side surface would be understood to be convex while a positive rd of 252.97534 for the image-side surface would be understood to be concave.

Example 5 modified to support F#=2.8 continues to maintain positive value radius of curvature values for both the object- and image-side surfaces of L1. Thus, even Example 5 modified to support F#=2.8 continues to yield a meniscus-shaped L1 lens.

	Thus, Ogino's Example 5 lens assembly whether alone or modified as above teaches "*wherein the first lens element has a convex object-side surface and a convex or concave image-side surface*" as recited by the claim.
Claim 18	
[18.0] The lens assembly of claim 17, wherein the TTL is equal or smaller than 6.0 mm	This limitation is the same as [2.0] and is disclosed for the same reasons discussed above.
[18.1] and wherein the lens assembly has a f-number F#<2.9.	This limitation is the same as [2.1] and is disclosed for the same reasons discussed above.
Claim 21	
[21.0] The lens assembly of claim 17, wherein the lens assembly has a f-number F# < 2.9.	This limitation is the same as [2.1] and is disclosed for the same reasons discussed above.
Claim 22	
[22.0] The lens assembly of claim 21, wherein lens element L_{1_1} has a concave image-side surface.	This limitation is the same as [6.0] and is disclosed for the same reasons discussed above.
Claim 23	
[23.0] The lens assembly of claim 17, wherein the lens assembly has a f-number F#=2.8.	This limitation is rendered obvious as discussed above in [2.1]. While the limitation in [2.1] has the "F#<2.9," the analysis above shows how Ogino's Example 5 lens assembly modified based on Bareau's teachings supports F#=2.8.

C. Claims 3, 8, 19, and 24 are obvious over the combination of Ogino, Bareau, and Kingslake.

1. Summary of Kingslake

60. Kinglake published in 1992 and is titled “Optics in Photography.” APPL-1013, Cover. In Chapter 11 titled “The Brightness of Images,” Kingslake indicates that “[t]he relation between the aperture of a lens and the brightness of the image produced by it … is often misunderstood, **yet it is of the greatest importance to the photographer who wishes to make the best use of the equipment**.” *Id.*, p.104. Kingslake then states that “[t]he tremendous efforts of lens designers and manufacturers that have been devoted to the production of lenses of extremely high relative aperture **are an indication of the need that exists for brighter images and ‘faster’ lenses**.” *Id.* Thus, as early as 1992, Kingslake indicates the need in the art to develop “faster” lenses (i.e., lower f-numbers) in order to produce brighter images. Lens designs with lower f-numbers were still in demand for use with digital image sensors in 2009. APPL-1025, pp.10-11 (“What is required is a lens system with a fairly low f/# to even theoretically achieve the sensor limited resolution.”).

2. Reasons to combine Ogino, Bareau, and Kingslake

61. It is my opinion that a POSITA would have found it obvious to modify Ogino’s Example 5 lens assembly to support a lower f-number (“F#” or “Fno”) based on (1) teachings from Ogino’s other embodiments showing an f-

number lower than Example 5, (2) teachings from Bareau (and Wang) of having an f-number of 2.8 **or less for small image sensors**, and (3) the teaching from Kingslake indication a general desire in the art to develop brighter lens systems with lower f-numbers. *See* APPL-1005, Figs. 8-13; APPL-1012, pp.3-4; APPL-1013, p.104; APPL-1024, 1:39-42. Such a modification of Example 5 would have been as simple as using lens design software and following the well-known lens design process explained in Fischer (APPL-1017) to find an optimized modification of Example 5 with a lower f-number consistent with Ogino's other embodiments.

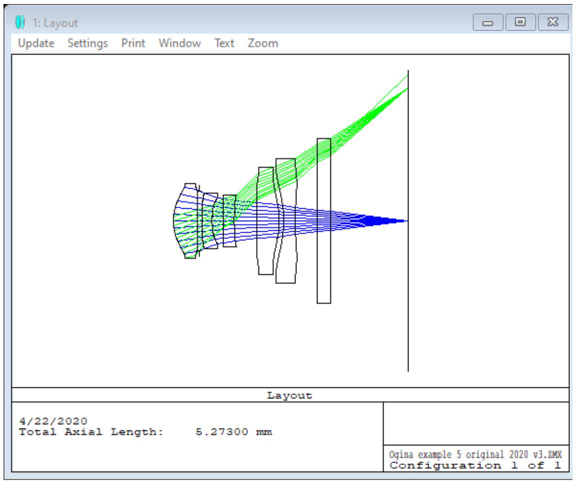
62. First, of Ogino's six examples, Example 5 has the highest F#=3.94. *See* APPL-1005, Figs. 8-13 (showing f-numbers of Examples 1-6). The f-numbers for Examples 1-3 and 6 (which all utilize a similar structure to Example 5), however, are much lower being respectively set at f-numbers 2.47, 2.46, 2.45, and 2.64. *See* APPL-1005, Figs. 8-10, 13. Based on this alone, a POSITA would have found it obvious to try to modify Ogino's Example 5 to see whether it would similarly support a lower f-number like F#=2.45.

63. Second, as discussed above in Bareau and Wang, POSITAs were well aware of modern cell phone specifications and the need to develop lens designs with f-numbers at or below 2.8 so that enough light would be provided to small sensor formats. This general desire to achieve a lower f-number is confirmed by

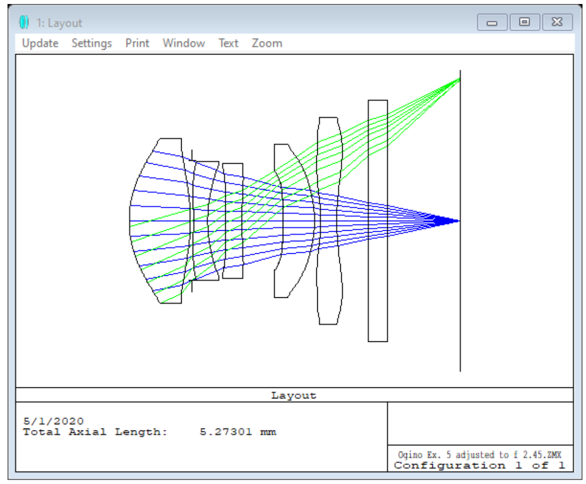
Kingslake which, as early as 1992, indicated the need for "faster" lenses: "The tremendous efforts of lens designers and manufacturers that have been devoted to the production of lenses of extremely high relative aperture are an indication of **the need that exists for brighter images and 'faster' lenses**." APPL-1013, p.104. Due to this general desire for faster lenses to support smaller sensor formats, a POSITA would have been motivated modify Ogino's Example 5 lens to determine whether Example 5 could support a lower f-number like F#=2.45.

64. Following the lens design process which includes using lens design software (*see* APPL-1017, p.171-76), a POSITA would have reasonably expected to arrive at a usable design since Ogino's Example 3 (F#=2.45) and Example 5 share similar characteristics like lens groupings and lens shapes. Also, given that Ogino's other examples all show lower f-numbers, a POSITA would have reasonably expected that Example 5's f-number could likewise be lower. Proof that a POSITA would have had a reasonable expectation of success is provided below where Example 5 is modified to support an F#=2.45. *See infra* Appendix, Fig. 3A.

65. Modifying Example 5 to achieve F#=2.45, as shown below, and using lens design software to find the best solution, a POSITA would have arrived at one possible lens design as shown below:



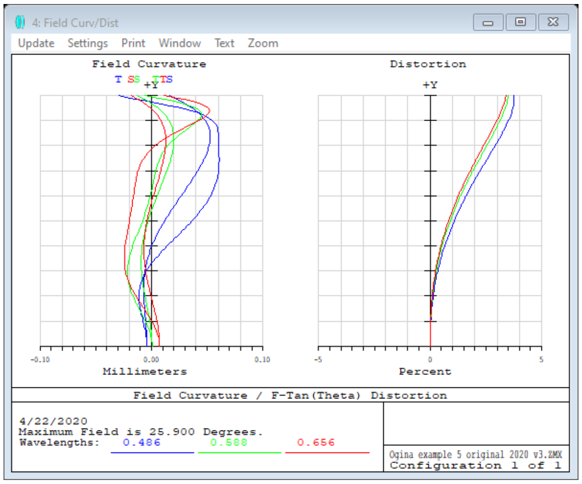
Ogino Example 5 (F#=3.94)



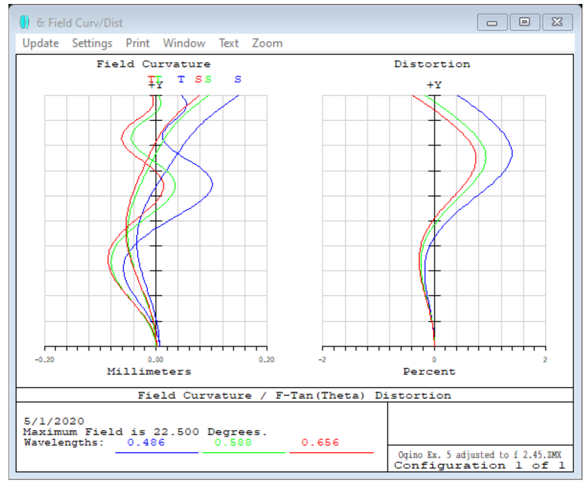
Example 5 modified with F#=2.45

See infra Appendix, Figs. 1A, 3A. This modified version of Example 5 uses larger lens diameter for each lens, which, as taught in Walker, is one way to lower the f-number of a lens assembly since increasing a lens's diameter allows more light to pass through the system while maintaining a similar focal length.

66. Modified Example 5 above supports an F#= 2.45 while maintaining similar performance characteristics and achieving higher relative illumination when compared to the original Example 5 design. This is shown by comparing the field curves and relative illumination plots below:

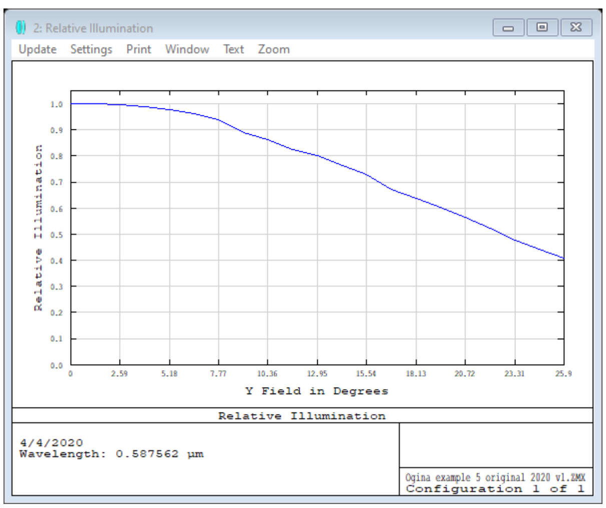


Ogino Example 5 (F#=3.94)

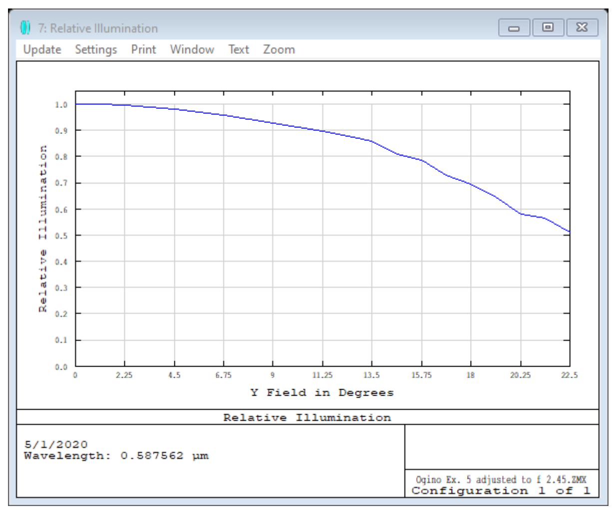


Example 5 modified with F#=2.45

See infra Appendix, Figs. 1C, 3C.



Relative Illumination of Ogino Example 5 (F#=3.94)



Relative Illumination of Example 5 modified with F#=2.45

See infra Appendix, Figs. 1B, 3B.

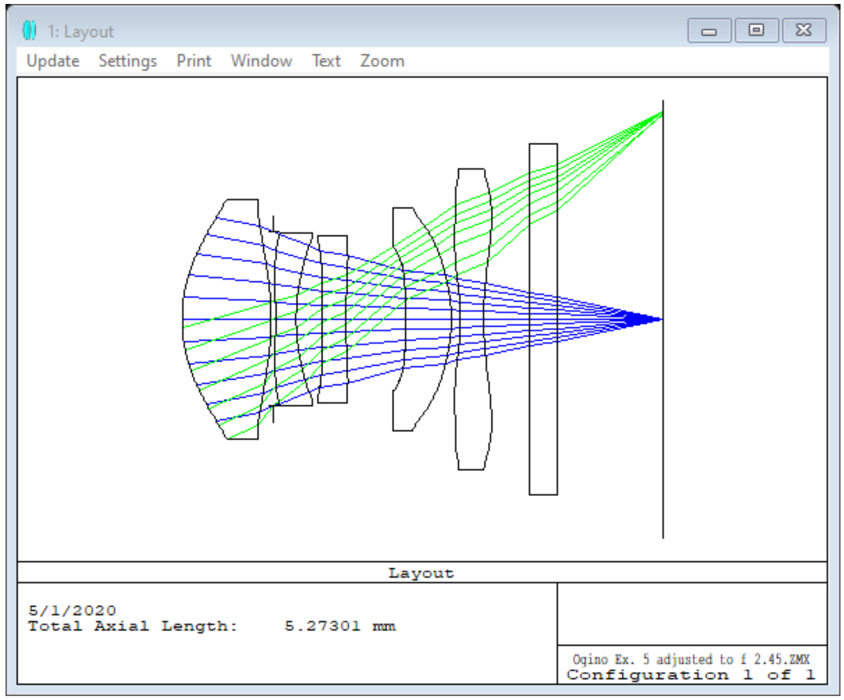
67. As by the Appendix below, Ogino modified for a lower f-number continues to meet all of the limitations of claim 1. Thus, a POSITA would have found it obvious, desirable, and predictable to lower the f-number of Ogino's

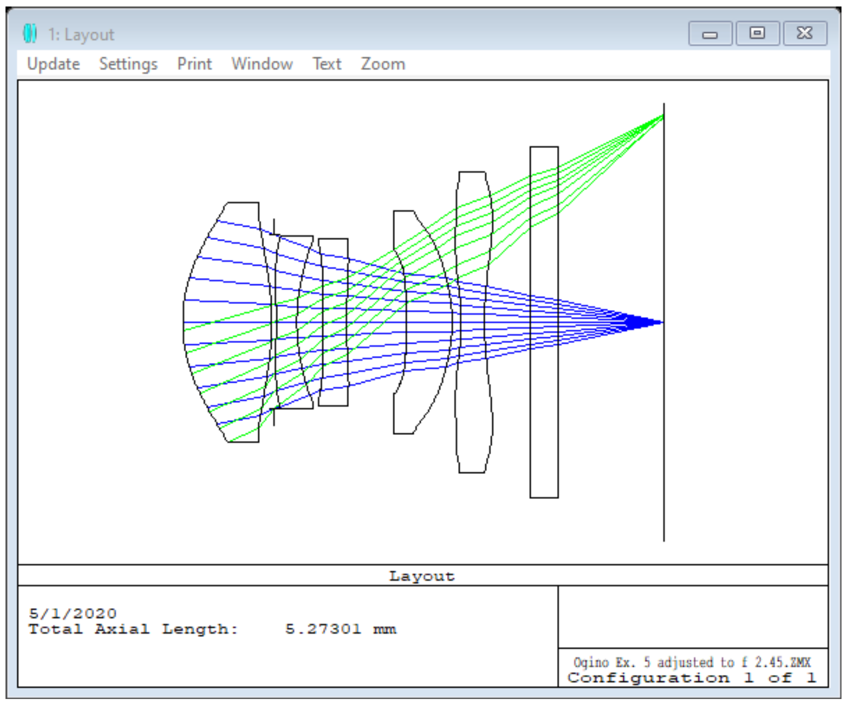
Example 5 lens assembly and would have succeeded in doing so as evidenced by the modified design above.

3. Detailed Analysis

68. In my opinion, Ogino Example 5 as modified to support a lower f-number renders obvious claims 3, 8, 19, and 24, as shown in the chart below:

Claim 3	
[3.0] The lens assembly of claim 1, wherein the TTL is equal or smaller than 6.0 mm	Ogino discloses this limitation because, as shown in [1.2], the Example 5 lens assembly has a TTL with the cover glass element of 5.273 mm which is less than 6.0 mm. In the modification above where Example 5 supports F#=2.45, the TTL is maintained to 5.273 mm as in Example 5 unmodified. *See infra* Appendix, Fig. 3A. Thus, Ogino's Example 5 modified to support a lower F# of 2.45 renders this limitation obvious.
[3.1] and wherein lens element L_{1_1} has an image-side surface diameter between 2.3 mm and 2.5 mm.	Ogino's Example 5 modified to support a lower f-number renders this limitation obvious. As shown above, a POSITA would have found it obvious to modify Example 5 to achieve a telephoto lens with a lower f-number. A POSITA would have found this modification to be both predictable and desirable due to Ogino's other disclosed embodiments supporting lower f-numbers (*see* APPL-1005, Figs. 8-13), the teaching of Bareau and Wang indicating a desire for cell phone lenses with lower f-number for smaller sensors (*see* APPL-1012, pp.3-4; APPL-1024, 1:39-42), and the teachings on Kingslake indicating a general desire among POSITAs to design faster lenses (*see* APPL-1013, p.104). Further, as also discussed above, a POSITA would have understood that one way to reduce the f-number of a lens design is to make the lens diameters larger so that more light can pass through the system. This is represented in

	the modification of Example 5 below that supports F#=2.45. Corresponding data is provided in the Appendix.  *See infra* Appendix, Fig. 3A. According to the data in the Appendix for this modification (*see* Fig. 3D), the semi-diameter for the image-side surface of L1 (i.e., L_{1_1}) is 1.170 mm. *See* Appendix, Fig. 3D (semi-diameter for surface 2). This yields a diameter of 2.34 mm, which falls between the claimed ratio of 2.3 mm and 2.5 mm. *Id.* Thus, Ogino's Example 5 modified to support a lower f-number renders obvious "*wherein lens element L_{1_1} has an image-side surface diameter between 2.3 mm and 2.5 mm*" as recited in the claim.
Claim 8	
[8.0] The lens assembly of claim 5, wherein lens element L_{1_1} has a convex image-side surface.	Ogino's Example 5 modified to support a lower f-number renders this limitation obvious. As shown above, a POSITA would have found it obvious to modify Example 5 to achieve a telephoto lens with a lower f-number. A POSITA would have found this modification to be both predictable and desirable due to

	Ogino's other disclosed embodiments supporting lower f-numbers (*see* APPL-1005, Figs. 8-13), the teaching of Bareau and Wang indicating a desire for cell phone lenses with lower f-number for smaller sensors (see APPL-1012, pp.3-4; APPL-1024, 1:39-42), and the teachings on Kingslake indicating a general desire among POSITAs to design faster lenses (*see* APPL-1013, p.104). Further, as also discussed above, a POSITA would have understood that one way to reduce the f-number of a lens design is to make the lens diameters larger so that more light can pass through the system. This is represented in the modification of Example 5 below that supports F#=2.45. Corresponding data is provided in the Appendix.  *See infra* Appendix, Fig. 3A. In this modified version of Example 5, the diameters of the lens elements and aperture have been slightly increased from the F#=2.8 design, which a POSITA would know would allow more light to enter the system. The radius of curvature for the image-side surface of L1 was also changed from concave to convex to allow the L1 lens to better focus incoming light, to provide a thicker edge for

	easier manufacturing (*see* APPL-1007, p.7) while maintaining its original focal length as much as possible. The L1 lens in the modification above has an rd of 1.607 for the object-side surface and an rd of -2.944 on the image-side surface. *See infra* Appendix, Fig. 3D. The L1 lens therefore is convex on both the object- and image-side surfaces. Thus, Ogino's Example 5 modified to support a lower f-number renders obvious "*wherein lens element L_{1_1} has an image-side surface diameter between 2.3 mm and 2.5 mm*" as recited in the claim.
Claim 19	
[19.0] The lens assembly of claim 17, wherein the TTL is equal or smaller than 6.0 mm	This limitation is the same as [3.0] and is disclosed by the prior art for the same reasons discussed above.
[19.1] and wherein lens element L_{1_1} has an image-side surface diameter between 2.3 mm and 2.5 mm.	This limitation is the same as [3.1] and is disclosed by the prior art for the same reasons discussed above.
Claim 24	
[24.0] The lens assembly of claim 21, wherein lens element L_{1_1} has a convex image-side surface.	This limitation is the same as [8.0] and is disclosed by the prior art for the same reasons discussed above.

D. Claims 16 and 30 are obvious over the combination of Chen, Iwasaki, and Beich.

1. Summary of Chen

69. Chen is directed to "an optical imaging lens set of five lens elements for use in mobile phones, in cameras, in tablet personal computers, or in personal digital assistants (PDA)." APPL-1020, 1:16-19. Chen's Example 1 is particularly relevant to claims 1 and 30 of the '897 Patent and is reproduced below:

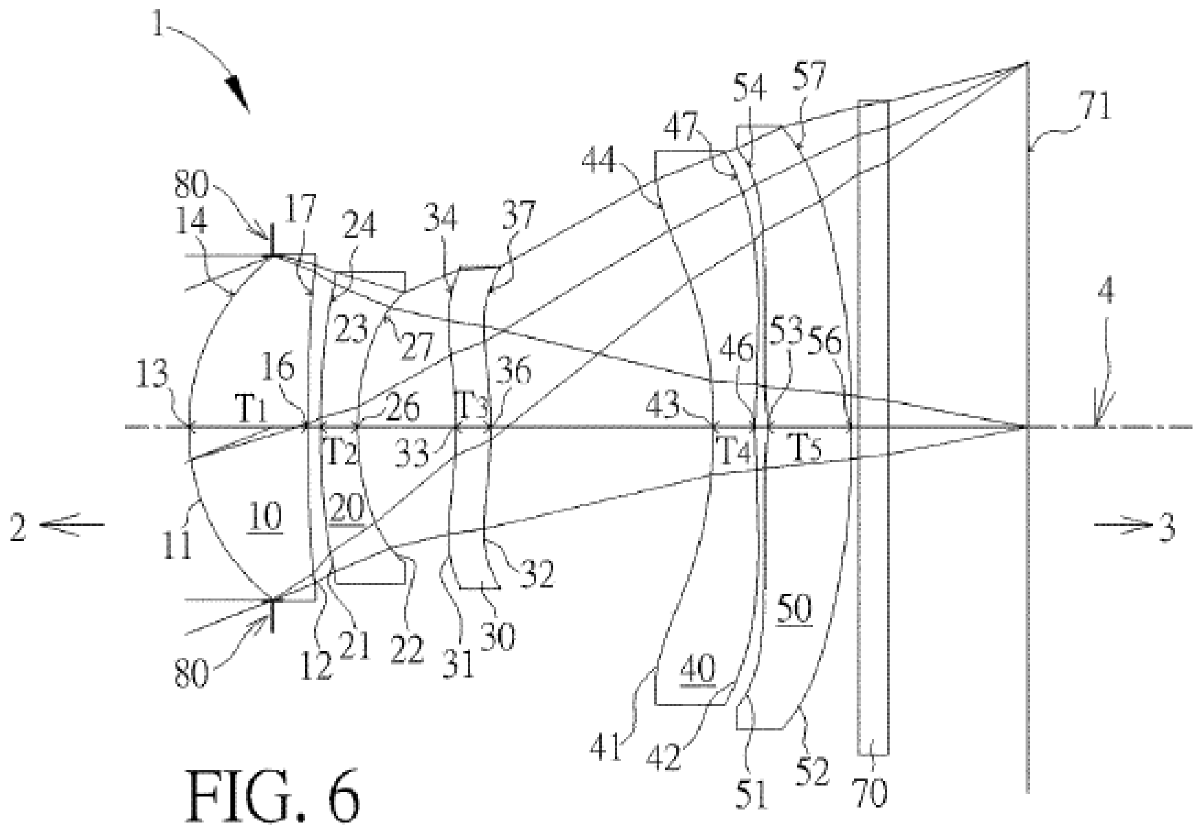


FIG. 6

Id., Fig. 6.

70. The prescription table describing Example 1 providing the thickness and spacing of each element along the optical axis and the focal length of each lens is similarly provided below:

First Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.565	0.855	T_1	1.545	55.987	2.975
		34.464	0.088	G_{12}			
21	Second Lens	6.079	0.264	T_2	1.642	22.409	-4.568
22		1.955	0.704	G_{23}			
31	Third Lens	-3.412	0.249	T_3	1.545	55.987	122.164
32		-3.330	1.598	G_{34}			
41	Fourth Lens	-4.283	0.310	T_4	1.545	55.987	-6.178
42		16.327	0.064	G_{45}			
51	Fifth Lens	-61.049	0.619	T_5	1.642	22.409	15.559
52		-8.680	0.050	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	1.007				
71	Image Plane	INFINITY					

Id., Fig. 24.

71. According to Chen, Example 1 has a focal length (f) of 6.582 mm, a total track length (TTL) of 6.0187 mm, and an f-number (Fno.) of 2.6614. *See id.*, 10:9-11, Fig. 42 (col. 1). Further, as discussed above in relation to the ’897 Patent, Chen similarly provides the sag equation and aspheric coefficients for Example 1 that can likewise be used to determine the edge thickness of each lens element. *Id.*, 9:49-67, Fig. 41.

2. *Summary of Iwasaki*

72. Iwasaki discloses "a fixed focus imaging lens for forming optical images of subjects" and is similar to Chen in that it is also designed for use in portable devices such as "a digital still camera, a cellular telephone with a built in camera, a PDA (Personal Digital Assistant), a smart phone, a tablet type terminal, and a portable gaming device." APPL-1009, 1:18-26. Iwasaki's lens system is also similarly designed to meet a "demand for miniaturization of the entirety of the photography devices as well as imaging lenses to be mounted there on" and to meet a "demand for high resolution and high performance of imaging lenses." *Id.*, 1:36-41.

73. All of Iwasaki's embodiments are listed as telephoto lenses, which is defined by the ratio of the total track length over the focal length of the lens system being less than one. *See id.*, 8:7-13; APPL-1006, p.169 (defining "telephoto ratio" as the focal length being longer than the overall lens length). Examples 1 and 2 of Iwasaki maintain this ratio by using a thinner cover glass element of 0.145 mm rather than using 0.210 mm or 0.300 mm thick cover glass used in Examples 3 and 4. *See* APPL-1009, Tables 1, 3, 5, 7. Despite Iwasaki's embodiments using cover glass of various thicknesses, the purpose remains the same as disclosed in Chen to "protect[] the imaging surface and an infrared cutoff filter." APPL-1009, 6:8-9. Thus, Iwasaki teaches a POSITA that a thinner cover glass element can be used in

a lens system to both reduce the total length while providing the same benefit of protecting the sensor and filtering infrared light.

3. Reasons to combine Chen and Iwasaki

74. A POSITA would have found it obvious and desirable to modify Chen's Example 1 lens system with Iwasaki's teaching of using a 0.145 mm cover glass element in a telephoto lens system. Such a combination would have both maintained the presence of a cover glass element in Example 1—for protecting the sensor and filtering infrared light, which Chen already teaches—while also further reducing the total length of the lens system. A POSITA would have been well aware that this modification simply required substituting the 0.210 mm cover glass element already present in Chen's Example 1 with a 0.145 mm element as taught in Iwasaki and adjusting the location of the image plane to correct for the thinner cover glass element (i.e., focus shift). This simple substitution would have been understood to yield the same predictable result as shown in Iwasaki of protecting the image sensor and filtering infrared light (which Chen teaches) while further reducing the total length of the lens system. An example of this modification is provided in the Appendix and shows that the total length of Example 1 with a 0.145 mm cover glass element is reduced from 6.019 mm to less than 6.0 mm.

75. As established above, while Chen and Iwasaki both disclose lens systems for mobile devices with a telephoto ratio of less than one (*see* APPL-1020,

Figure 42 (showing the “TLL/f<1” for all embodiments); APPL-1009, Table 9 (showing the “TL/f” ratio for all examples)), Iwasaki differs from Chen, in that Iwasaki’s examples use cover glass elements of various thickness from 0.145 mm to 0.300 mm where Chen’s all use cover glass of 0.210 mm. *See* APPL-1009, Tables 1, 3, 5, 7; APPL-1020, Fig. 42 (row labeled “TF”).

76. Since Chen identifies the need for “improved imaging quality with reduced lens set size,” a POSITA would have recognized that further reduction of the total length could be achieved by simply using a thinner cover glass element, as shown in Iwasaki. Using a lens design program such as Code V or Zemax, a POSITA could have modeled this replacement, as shown below, which does in fact meet both Chen’s and Iwasaki’s suggestion for including a cover glass element to filter infrared light. Thus, a POSITA would have expected success and, as shown below, would have been successful in reducing the thickness of the Example 1 cover glass from 0.210 mm as shown in Fig. 24 to 0.145 mm as shown in Iwasaki’s Examples 1 and 2.

4. Summary of Beich

77. Beich is directed to manufacturing considerations for “polymer optics,” which are optics “made of plastic and through the process of injection molding ….” APPL-1007, p.2. Such optics “provid[e] customized solutions to unique engineering and product problems.” *Id.* This “allow[s] the deployment of

sophisticated devices with increasingly complex optics on a cost competitive basis.” *Id.*

78. Beich states that its purpose is to instruct lens designers of “best practices when working with a polymer optics manufacturer.” *Id.* While injection molded optics provide several advantages, Beich states that it remains important for designers “to understand the manufacturing process behind these solutions so that they can design their programs to leverage the technology.” *Id.* This leads to a number of manufacturing considerations or “rules of thumb” based on the reality that “overall shape and tolerances of the optic will drive cost and manufacturability.” *Id.*, p.7. These rules of thumb consider several factors such as “thicker parts take longer to mold than thinner parts” and “[o]ptics with extremely thick centers and thin edges are very challenging to mold.” *Id.* As relevant to my analysis here, Beich teaches that a “rule of thumb” for “Center Thickness to Edge Thickness Ratio” is “< 3:1”, *i.e.*, the center thickness should be less than three times the edge thickness. *Id.*

Attribute	Rules of Thumb Tolerances
Radius of Curvature	± 0.50%
EFL	± 1.0%
Center Thickness	± 0.020mm
Diameter	± 0.020mm
Wedge (TIR) in the Element	< 0.010mm
S1 to S2 Displacement (across the parting line)	< 0.020mm
Surface Figure Error	≤ 2 fringes per 25.4mm (2 fringes = 1 wave @ 632nm)
Surface Irregularity	≤ 1 fringes per 25.4mm (2 fringes = 1 wave @ 632nm)
Scratch-Dig Specification	40-20
Surface Roughness (RMS)	≤ 100 Å
Diameter to Center Thickness Ratio	< 4:1
Center Thickness to Edge Thickness Ratio	< 3:1
Part to Part Repeatability (in a one cavity mold)	< 0.50%

Table 2. Rules of thumb.

Desirable Center-to-Edge Thickness Ratio

Id. Consequently, a POSITA looking to implement optical element specifications using injection molding methods would look to Beich for guidance on limitations and parameters that affect lens manufacturability.

5. *Reasons to combine Chen and Beich*

79. It is my opinion that a POSITA would have combined the teachings of Chen and Beich because such a combination would have been nothing more than using Beich's "rules of thumb" to make design choices to aid in the manufacturability of Chen's Example 1 lens assembly. Specifically, a POSITA looking to manufacture Example 1 would have considered Beich's rule of thumb for maintaining a desirable center-to-edge thickness ratio for the L1 lens element, which would aid in selecting the lens's diameter to maintain sufficiently uniform thickness for easier manufacturing. Applying Beich's manufacturing considerations to Example 1 in this way would have yielded the predictable result

of the L1 lens maintaining a center-to-edge thickness ratio of less than 3.0 as already taught by Chen's Example 1 design. *See* Appendix, Fig. 4E (showing edge thickness data for L1 of 0.293 mm (from surface 3 to 4) yielding a ratio of 2.92 given that the lens center thickness is 0.855 mm).

80. As shown above in the prescription table for Chen's Example 1, the first lens L1 has a thickness of 0.855 millimeters. *See id.*, Fig. 24. While Chen does not discuss manufacturing or materials of its lens elements, a POSITA would have recognized that only a few methods and materials would have been used to craft such small aspheric components. One such method is to manufacture plastic lenses through injection molding, which is "the preferred polymer manufacturing technology for optical elements having a diameter smaller than 0.1 m and a thickness not greater than 3 cm." APPL-1019, p.34.14. In addition to size considerations, a POSITA would have recognized that the refractive index and Abbe number of the lens elements in Example 1 are within the range of values of plastic materials used in injection molding manufacturing. *See* APPL-1018, p.27.

81. Since Example 1 would preferably have been manufactured via injection molding, as discussed above, and to the extent that Chen does not provide manufacturing parameters, a POSITA would have looked to polymer injection molding references such as Beich, which "discuss[es] the polymer optics manufacturing process and examine[s] the best practices to use when working with

a polymer optics manufacturer." APPL-1007, p.2. According to Beich, lens manufactures rely on "rules of thumb," as discussed above, in manufacturing lens elements to maintain the ratio of center thickness to edge thickness to a value less than three ("< 3:1"). *Id.*, p.7. This is because "[o]ptics with extremely thick centers and thin edges are very challenging to mold." *Id.* The "center thickness" and "edge thickness" in Beich correspond to the "largest optical axis thickness L11" and the "circumferential edge thickness L1e" in the '897 Patent.

82. A POSITA would have recognized that Chen does not specify the diameters of its respective lens elements, thus leaving it as a design choice based on manufacturability. As a result, the L1 lens in Example 1—with a thick center and edges that grow thinner as the lens diameter increases—is of the type for which a POSITA would manufacture so that the ratio of center thickness to edge thickness is less than 3:1. In other words, to maintain the desirable 3:1 ratio, a POSITA would have known to allow for lens diameter so that, at a minimum, the lens would function for its intended purpose of passing through all intended light rays while being easier to manufacture. This is evidenced by the L1 lens, as originally designed, having an edge thickness of 0.293 as calculated by Zemax that thus yields a center-to-edge thickness ratio (0.855/0.293) of about 2.92. *See infra* Appendix, Fig. 4E.

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	power is defined as the inverse of the focal length. *See* APPL-1010, p.159, footnote. Thus, Chen's Example 1 teaches "*wherein lens element L_{1_1} has positive refractive power and lens element L_{1_2} has negative refractive power*."
Claim 2	
[2.0] The lens assembly of claim 1, wherein the TTL is equal or smaller than 6.0 mm and	The combination of Chen and Iwasaki renders this limitation obvious because, as discussed above in [1.2], Chen's Example 1 with a thinner cover glass as taught in Iwasaki shows a TTL of 5.985 mm. *See infra* Appendix, Fig. 4A. Thus, the combination of Chen's Example 1 with a thinner glass plate as taught in Iwasaki renders obvious "*wherein the TTL is equal or smaller than 6.0 mm*."
[2.1] wherein the lens assembly has a f-number F#<2.9.	Chen discloses this limitation because Example 1 has an f-number (F#) of 2.661. *Id.*, 13:17-18, Fig. 42. Thus, Chen's Example 1 lens system teaches "*wherein the lens assembly has a f-number F#< 2.9.*"
Claim 16	
[16.0] The lens assembly of claim 2, wherein the lens assembly further includes a ratio between a largest optical axis thickness L11 and a circumferential edge thickness L1e of lens element L_{1_1} of L11/Lle<3.	The combination of Chen and Beich renders this limitation obvious. A POSITA would have understood that the L1 lens in Chen's Example 1 is design so that the center-to-edge thickness would be less than three when manufactured. In fact, the Zemax model of Example 1 below, shows that the L1 lens has a center thickness of 0.855 mm (*see* Fig. 24) and an edge thickness of 0.293 mm yielding a center-to-edge thickness ratio of 2.92. *See infra* Appendix, Fig. 4E. Based on the teaching of Beich, a POSITA would have sought to limit the diameter of the first lens so that the center-to-edge thickness would be maintained below three

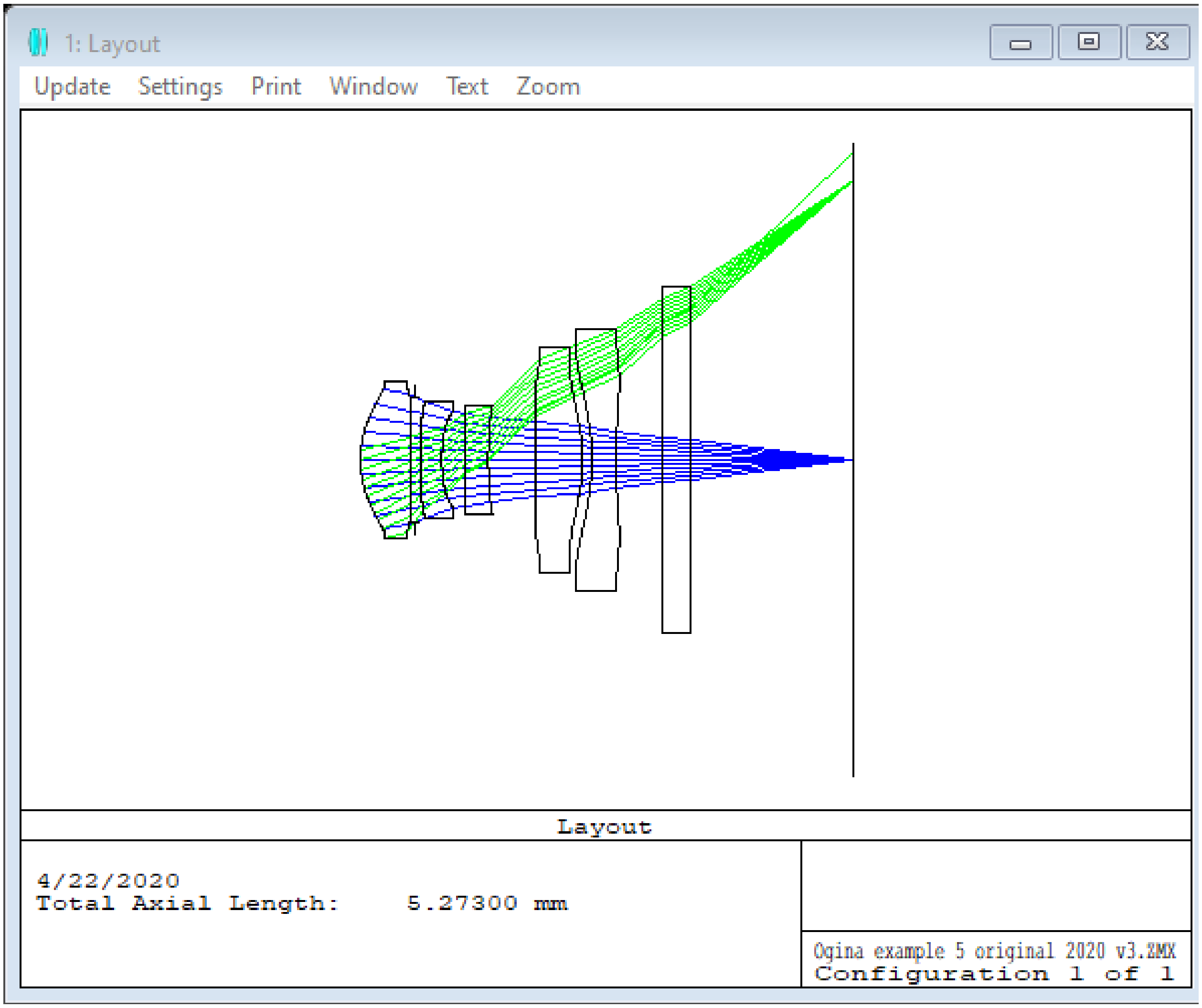
U.S. 10,330,897	Chen, Iwasaki, and Beich
	to provide for easier manufacturing using the plastic injection molding process. APPL-1007, p.7. In more detail and as discussed above, the '647 Patent states that the center-to-edge thickness ratio can be determined by using the thickness of the first lens (i.e., L11), the aspheric data provided for each surface of the first lens, and the radius of the first lens: Using the data from row #2 in Tables 1 and 2, L1e in lens element 102 equals 0.297 mm, yielding a center-to-edge thickness ratio L11/ L1e of 3.01. APPL-1001, 5:21-23. Using this same method with the sag equation, the thickness of the first lens, the aspheric data for each surface of the first lens, and the diameter of the first lens, a POSITA would have recognized that the same ratio can be determined for Chen's Example 1. In Example 1, the thickness of the first lens is 0.855 mm as shown in Fig. 24 and the aspheric data for each surface of the first lens is provided in the columns marked "11" and "12" in Fig. 25. Chen, however, does not provide a diameter for the first lens. For this reason, a POSITA considering the manufacturability of Chen would have determined the diameter of the first lens such that the lens would cover the aperture (to allow light passing through the aperture to enter the lens system) but would also be easy to manufacture. A shown in the Zemax calculated model below, a POSITA would have determined the center-to-edge thickness ratio (0.855/0.293) to be 2.92 which is less than the claimed ratio of three and consistent with Beich's teaching. *See infra* Appendix, Fig. 4E (surface 3) Because Example 1 already meets Beich's preferred center-to-edge thickness ratio of less than 3.0, a POSITA would have understood the need to constrain the diameter so that Beich's center-to-edge thickness ratio would be

U.S. 10,330,897	Chen, Iwasaki, and Beich
	maintained since the ratio increases as the diameter increases due to the shape of the lens. Put another way, as the diameter of the first lens in Example 1 increases, the edge becomes thinner due to the shape. In cases like this, according to Beich, "[o]ptics with extremely thick centers and thin edges are very challenging to mold." APPL-1007, p.7. Beich thus suggests that for ease of manufacturing, the center-to-edge thickness ratio should be maintained at less than 3:1, which Chen's Example 1 already provides. A POSITA knowing of this issue with manufacturability would have thus been motivated to constrain the diameter of the first lens so that this desirable ratio would be maintained. Based on these teaching from Beich, a POSITA using the sag equation and the data provided for Example 1 in Chen would have determined the diameter of the first lens that could be achieved while still maintaining a desirable center-to-edge thickness. A POSITA thus would have been motivated to set the first lens element's diameter to support the aperture opening but to maintain Beich's desirable ratio. Thus, based on the design of the first lens in Example 1 of Chen and the teaching of Beich, a POSITA would have selected a diameter best suited to support the aperture opening and for mounting while keeping the center-to-edge thickness ratio at less than 3 for ease of manufacturing. Consequently, a POSITA would have found it obvious to set the diameter of the first lens in Chen's Example 1, which would maintain the center-to-edge thickness ratio at less than 3 Thus, Chen's Example 1 lens system combined with Beich's teaching of limiting the center-to-edge thickness ratio of a positive lens to less than 3:1 renders obvious "*wherein the lens assembly further includes a ratio between a largest optical axis thickness L11 and a circumferential edge thickness L1e of lens element* L_1 *of L11/Lle<3*."

IX. APPENDIX

A. Ogino Example 5 using Zemax (v. 02/14/2011)

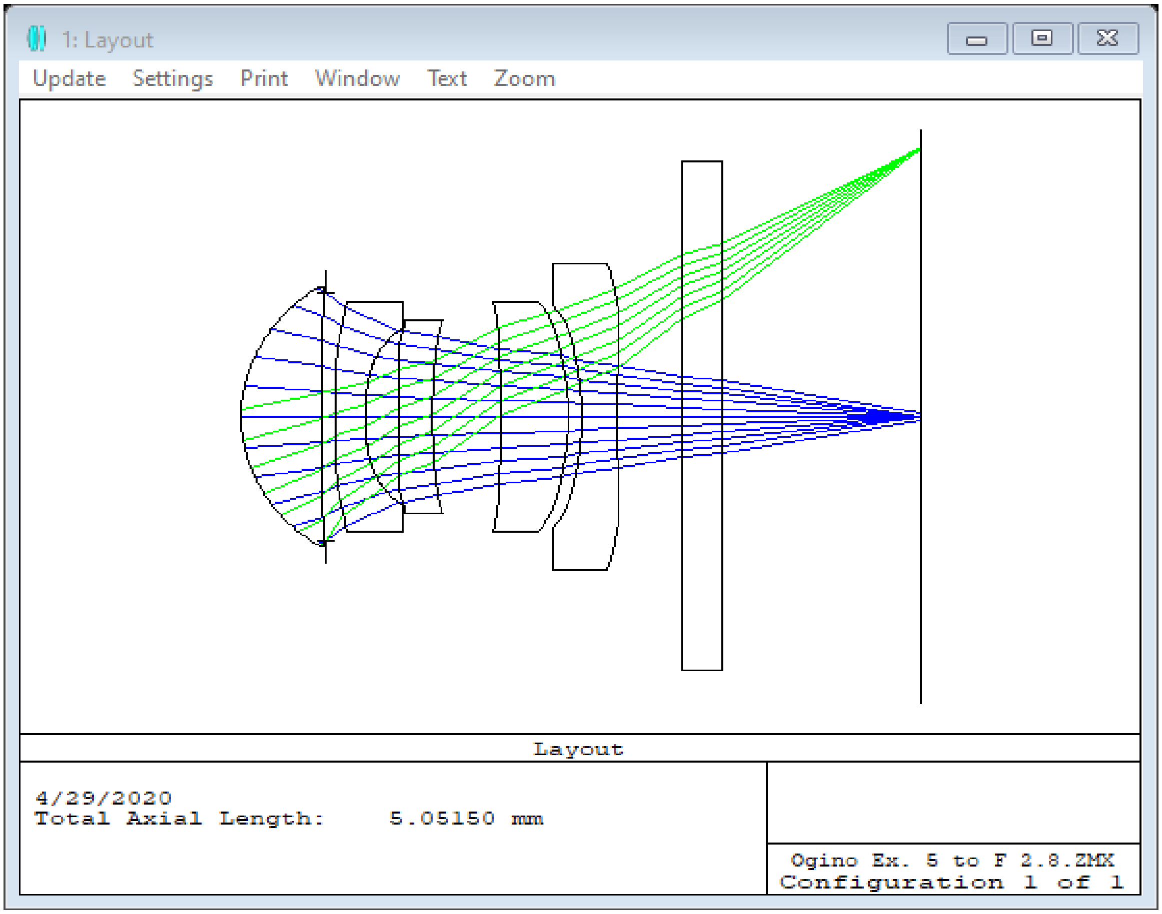
1. Fig. 1A – Ray Trace Diagram



* Prescription data as provided in Ogino (APPL-1005) Tables 9 and 10.

B. Ogino Example 5 modified for F#=2.8 using Zemax (v. 02/14/2011)

1. Fig. 2A – Ray Trace Diagram



Steps for modification:

1) Open the aperture to support f-number at 2.8 and set FOV to +/- 20°;
2) Allow vignetting as in Ogino's original design;
3) f2-f5 unchanged; f1 increased by 0.0001 due to L1 thickness change;
4) Thickness of L1 increased to avoid negative thickness at the edge.
5) Software-optimized for image quality using conic constants and aspheric coefficients;
6) Image height is 2.06 mm. Or 2.31 mm after lens scaling by a factor of 1.12 to accommodate for a ¼" sensor with a diagonal of 2 X 2.2 mm.

EFL=5.648, TTL=5.051, EPD=2.0171 mm, and thickness and spacing of L2-L5 remain unchanged (data calculated for standard wavelength of 587 nm).

4. *Fig. 2D – Prescription Data*

Lens Data Editor

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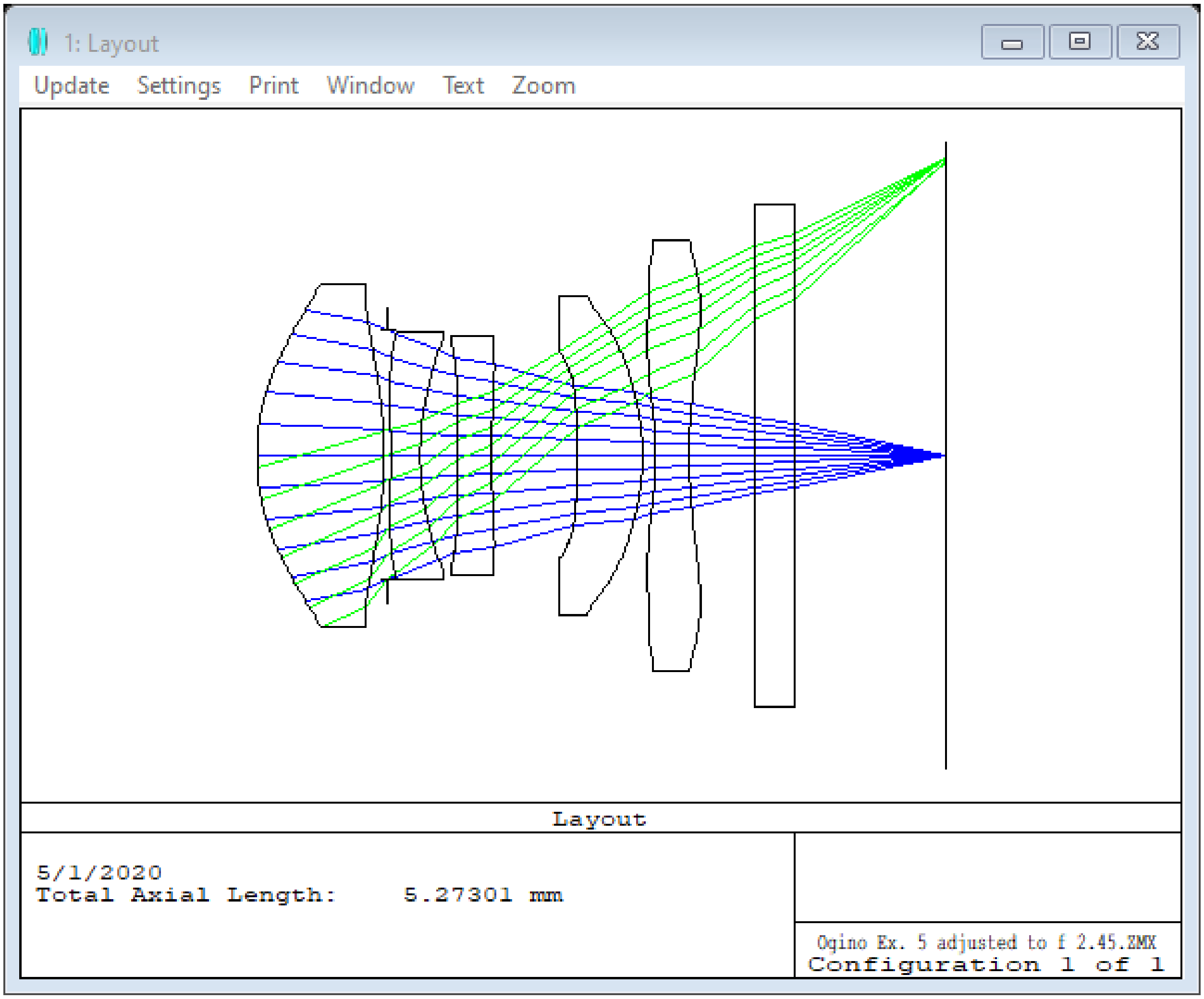
Surf:Type		Comment	Radius		Thickness		Glass		Semi-Diameter		Conic		Par 0(
OBJ	Standard		Infinity		Infinity				Infinity		0.000000000		
1	Even Asph..		1.124440000		0.600000000		1.54,54.9		1.017495713		-0.02321058	V	
2	Even Asph..		252.9753400		0.030000000				0.989430468		9.0000E-006		
STO	Standard		Infinity		0.069000000				0.976140598		0.000000000		
4	Even Asph..		-18.7883600		0.227000000		1.63,23.6		0.900414025		8.807373100		
5*	Even Asph..		2.256160000		0.243000000				0.700000000	U	2.118203900		
6	Even Asph..		506.4558100		0.253000000		1.63,23.6	P	0.705945685		-0.38118373		
7	Even Asph..		4.365600000		0.506000000				0.754534746		-2.100E-007		
8*	Even Asph..		-99.8371500		0.506000000		1.63,23.6	P	0.900000000	U	-0.67741896		
9*	Even Asph..		-1.70702000		0.100000000				0.900000000	U	-3.62920100		
10*	Even Asph..		-2.17464000		0.253000000		1.54,54.9	P	0.870000000	U	-15.0000200		
11*	Even Asph..		3.614290000		0.500000000				1.200000000	U	-0.86999414		
12*	Standard		Infinity		0.300000000		1.52,64.1		2.000000000	U	0.000000000		
13*	Standard		Infinity		1.464496011	M			2.000000000	U	0.000000000		
IMA	Standard		Infinity		-				2.250000000	U	0.000000000		

unused)		Par 1(unused)		Par 2(unused)		Par 3(unused)		Par 4(unused)		Par 5(unused)		Par 6(unused)		Par 7(unuse
		0.000000000		-0.01032345	V	-0.03890334	V	0.000000000		0.000000000		0.000000000		0.0000000
		0.000000000		0.015319514	V	4.9453E-003	V	0.000000000		0.000000000		0.000000000		0.0000000
		0.000000000		0.392107473	V	-0.28617070	V	0.000000000		0.000000000		0.000000000		0.0000000
		0.000000000		0.585567623	V	0.112886741	V	0.000000000		0.000000000		0.000000000		0.0000000
		0.000000000		-0.05341669	V	0.444181113	V	0.000000000		0.000000000		0.000000000		0.0000000
		0.000000000		-0.15910275	V	0.341877892	V	0.000000000		0.000000000		0.000000000		0.0000000
		0.000000000		-0.03172275	V	-0.04978430	V	0.000000000		0.000000000		0.000000000		0.0000000
		0.000000000		0.278658518	V	-0.37632548	V	0.000000000		0.000000000		0.000000000		0.0000000
		0.000000000		0.062506812	V	-0.30238471	V	0.000000000		0.000000000		0.000000000		0.0000000
		0.000000000		-0.20306060	V	0.054277904	V	0.000000000		0.000000000		0.000000000		0.0000000

C. Ogino Example 5 modified for F#=2.45 using Zemax (v. 02/14/2011)

1. Fig. 3A – Ray Trace Diagram



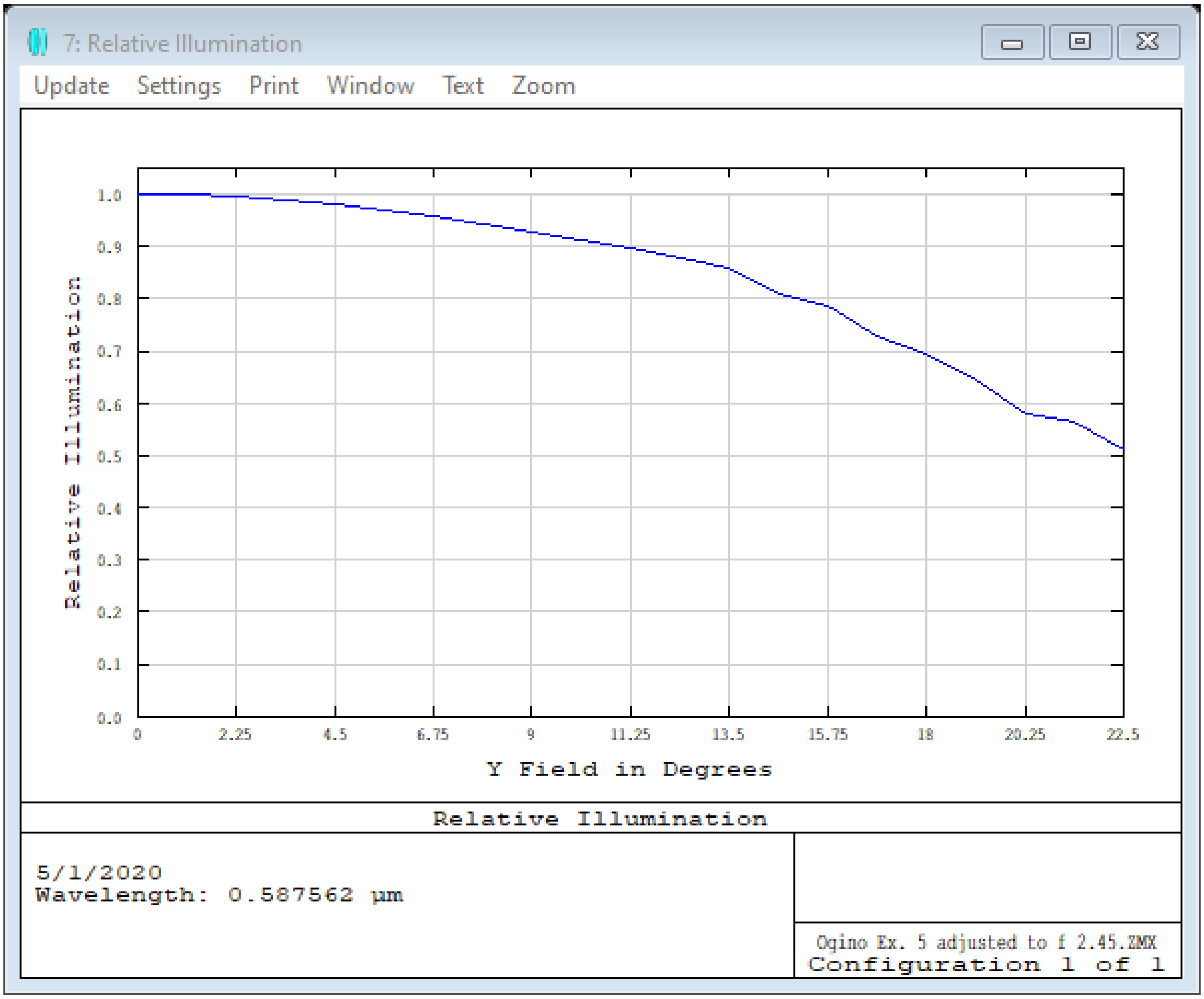
Steps for modification:

1) Starting with Ogino Ex. 5 at F#=2.8;
2) Re-optimize lens with only lens L1 radii (due to location of the aperture), airspaces, and aspheric coefficients;
3) Optimize for image quality and a thicker L1 edge for ¼” sensor diagonal.

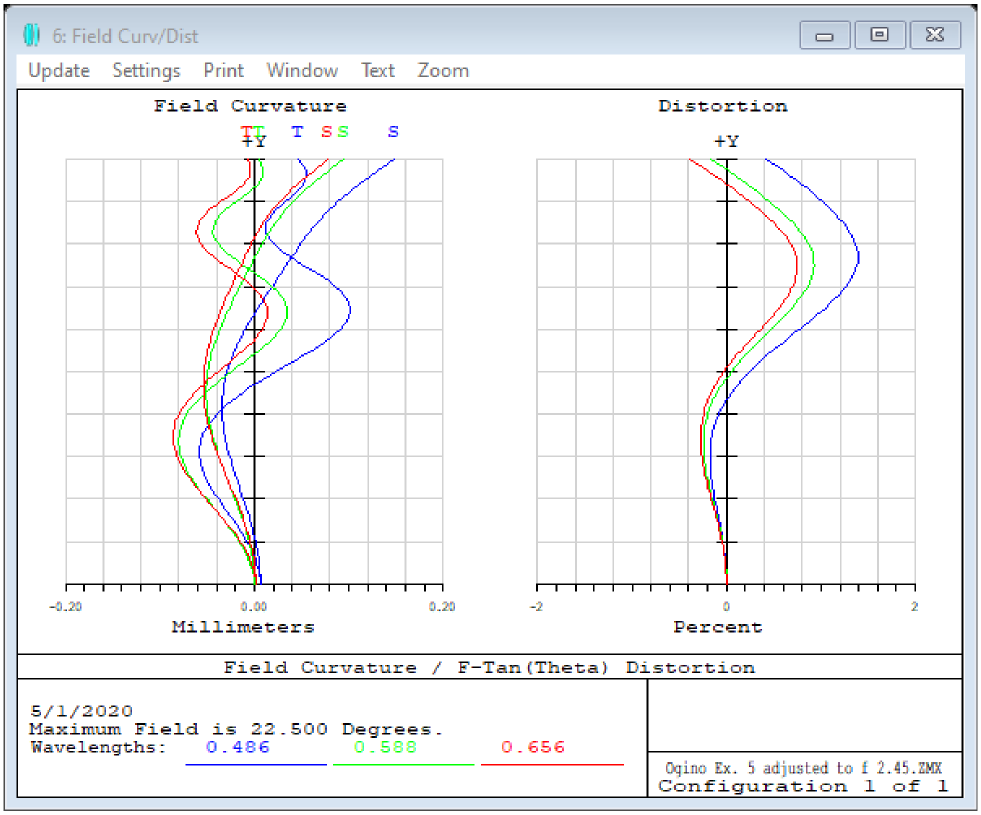
EFL=5.49; TTL=5.273; EPD=2.59; F#=2.12; f1=2.064 mm; f2-f5 remain unchanged (data calculated for standard wavelength of 587 nm).

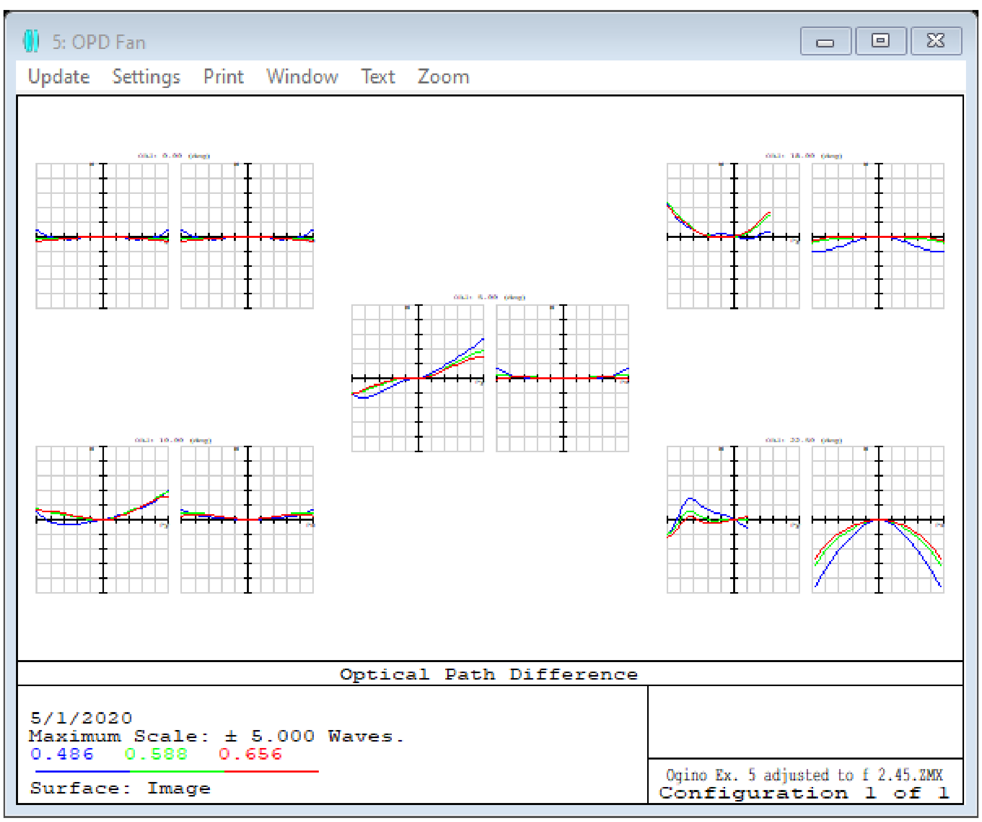
D7/EFL=0.12

2. *Fig. 3B – Relative Illumination*



3. *Fig. 3C – Analysis*





4. *Fig. 3D – Prescription Data*

Lens Data Editor

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Surf:Type		Comment	Radius	Thickness	Glass	Semi-Diameter	Conic	Par 0 (unus
OBJ	Standard		Infinity	Infinity		Infinity	0.000000000	
1	Even Asph..		1.606950699	0.975565111	1.54,54.9	1.317712916	-4.07878275 V	
2	Even Asph..		-2.94377806	0.029999192		1.170486227	0.000000000	
STO	Standard		Infinity	0.017175725		0.955456687	0.000000000	
4	Even Asph..		-18.7883600	0.227000000	1.63,23.6	0.951406227	0.000000000	
5	Even Asph..		2.256160000	0.289547566		0.891412894	0.000000000	
6	Even Asph..		506.4558100	0.253000000	1.63,23.6 P	0.889879802	0.000000000	
7	Even Asph..		4.365600000	0.652614911		0.911056103	0.000000000	
8*	Even Asph..		-99.8371500	0.506000000	1.63,23.6 P	0.800000000 U	0.000000000	
9	Even Asph..		-1.70702000	0.100000000		1.219549285	0.000000000	
10	Even Asph..		-2.17464000	0.253000000	1.54,54.9 P	1.573454378	0.000000000	
11	Even Asph..		3.614290000	0.500000000		1.653346230	0.000000000	
12	Standard		Infinity	0.300000000	1.52,64.1	1.851464027	0.000000000	
13	Standard		Infinity	1.169108706 M		1.927481189	0.000000000	
IMA	Standard		Infinity	-		2.395789268	0.000000000	

Par 0 (unused)	Par 1 (unused)	Par 2 (unused)	Par 3 (unused)	Par 4 (unused)	Par 5 (unused)	Par 6 (unused)	Par 7 (unus
	0.000000000	0.093561192 V	-0.03529572 V	0.000000000	0.000000000	0.000000000	0.0000000
	0.000000000	0.071236211 V	-0.01583453 V	0.000000000	0.000000000	0.000000000	0.0000000
	0.000000000	0.037677677 V	0.057351146 V	0.000000000	0.000000000	0.000000000	0.0000000
	0.000000000	-9.374E-003 V	-7.293E-004 V	0.000000000	0.000000000	0.000000000	0.0000000
	0.000000000	-0.06391311 V	-0.13033173 V	0.113959785 V	0.000000000	0.000000000	0.0000000
	0.000000000	-0.14858261 V	-0.02520141 V	0.087701329 V	0.000000000	0.000000000	0.0000000
	0.000000000	-0.21251272 V	-0.26430735 V	0.316517423 V	-0.30138838 V	0.000000000	0.0000000
	0.000000000	0.112964355 V	-0.03261618 V	-0.07830211 V	0.044638637 V	0.000000000	0.0000000
	0.000000000	0.302551856 V	-0.13853925 V	6.9798E-003 V	0.013469024 V	-2.683E-003 V	0.0000000
	0.000000000	-0.06055831 V	3.0126E-004 V	6.3498E-003 V	-5.182E-003 V	1.1691E-003 V	0.0000000

US009128267B2

(12) **United States Patent**
Ogino et al.

(10) **Patent No.: US 9,128,267 B2**
(45) **Date of Patent: Sep. 8, 2015**

(54) **IMAGING LENS AND IMAGING APPARATUS INCLUDING THE IMAGING LENS**

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CPC ***G02B 13/0045*** (2013.01)

(58) **Field of Classification Search**
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USPC 359/714
See application file for complete search history.

(56) **References Cited**

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(74) *Attorney, Agent, or Firm* — Young & Thompson

(57) **ABSTRACT**

An imaging lens substantially consists of, in order from an object side, five lenses of a first lens that has a positive refractive power and has a meniscus shape which is convex toward the object side, a second lens that has a biconcave shape, a third lens that has a meniscus shape which is convex toward the object side, a fourth lens that has a meniscus shape which is convex toward the image side; and a fifth lens that has a negative refractive power and has at least one inflection point on an image side surface. Further, the following conditional expression (1) is satisfied.

$$1.4<f/f1<4 \quad (1)$$

21 Claims, 14 Drawing Sheets

EXAMPLE 1

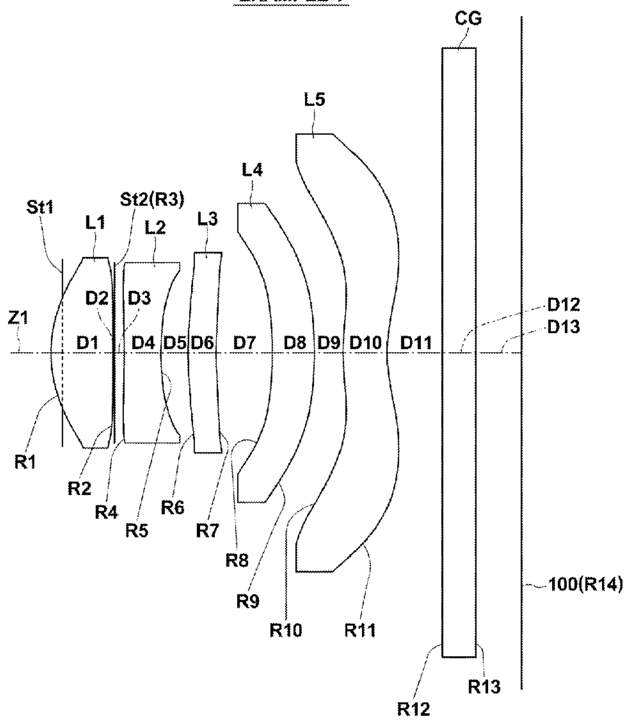


FIG.1

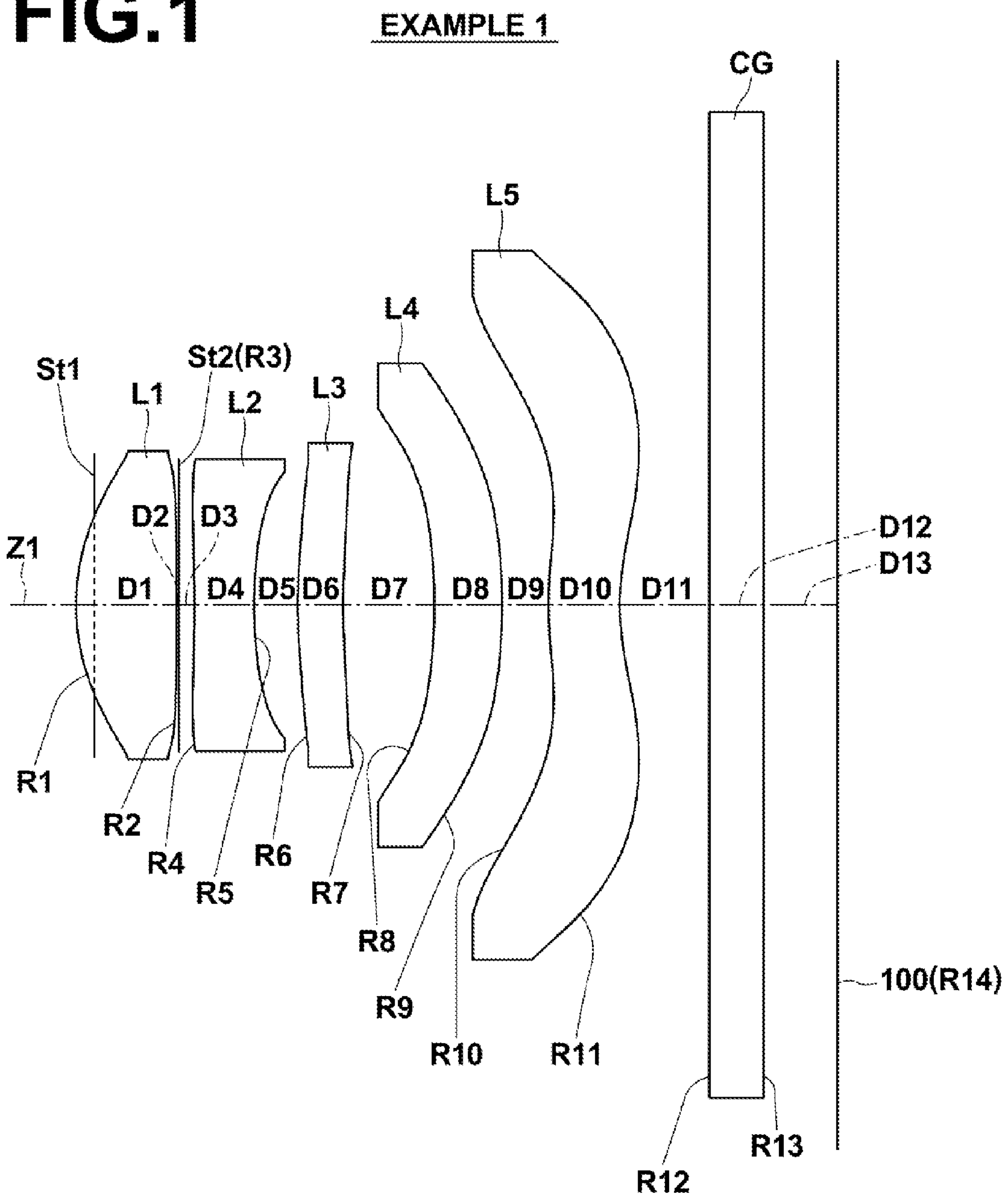

EXAMPLE 1
CG
L5
L4
St2(R3)
St1
L1
L2
L3
D2
D3
Z1
D1
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
R1
R2
R4
R5
R6
R7
R8
R9
R10
R11
100(R14)
R12
R13

FIG.2

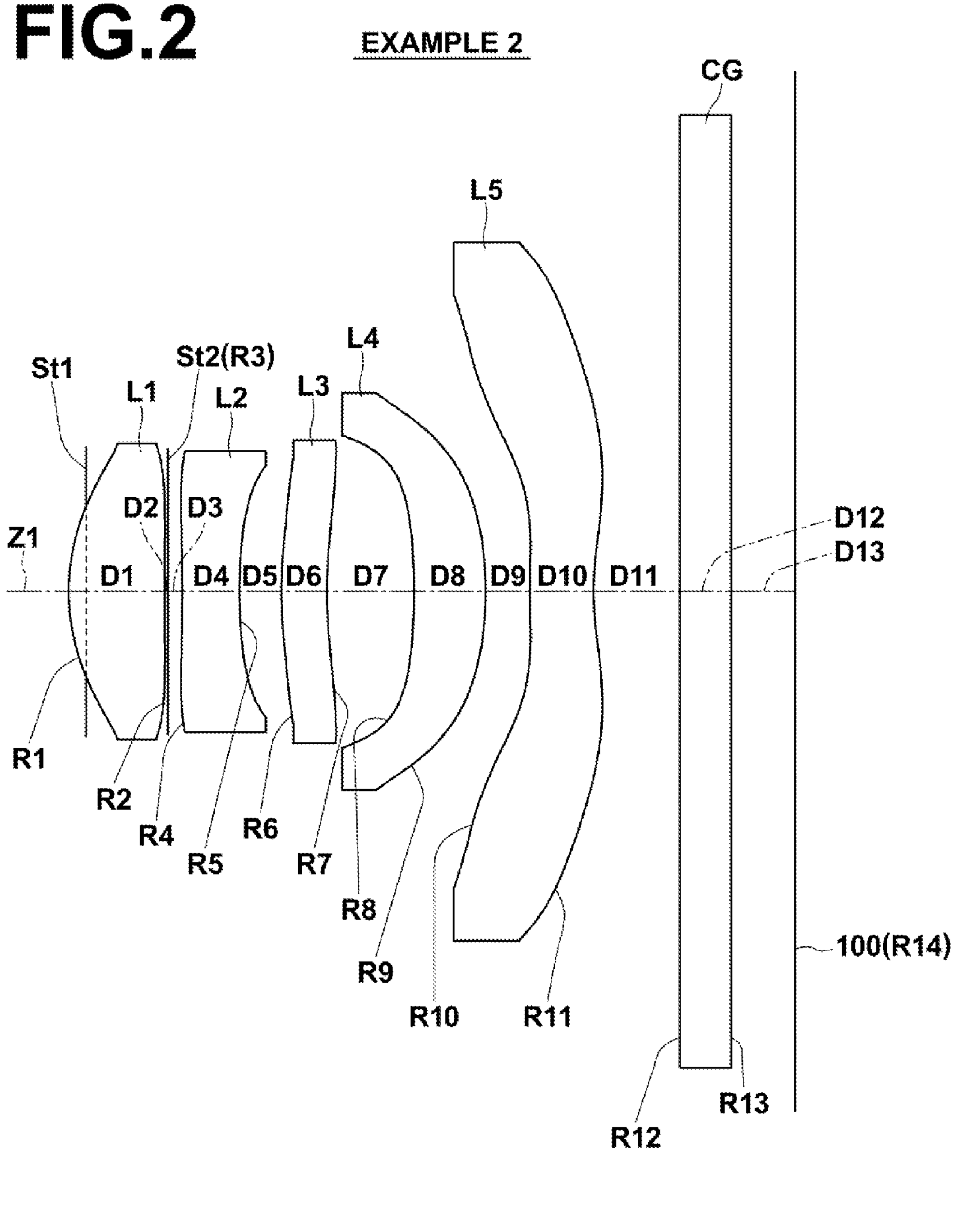

EXAMPLE 2
CG
L5
L4
St2(R3)
St1
L1
L2
L3
D2
D3
Z1
D1
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
R1
R2
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
100(R14)

FIG.3

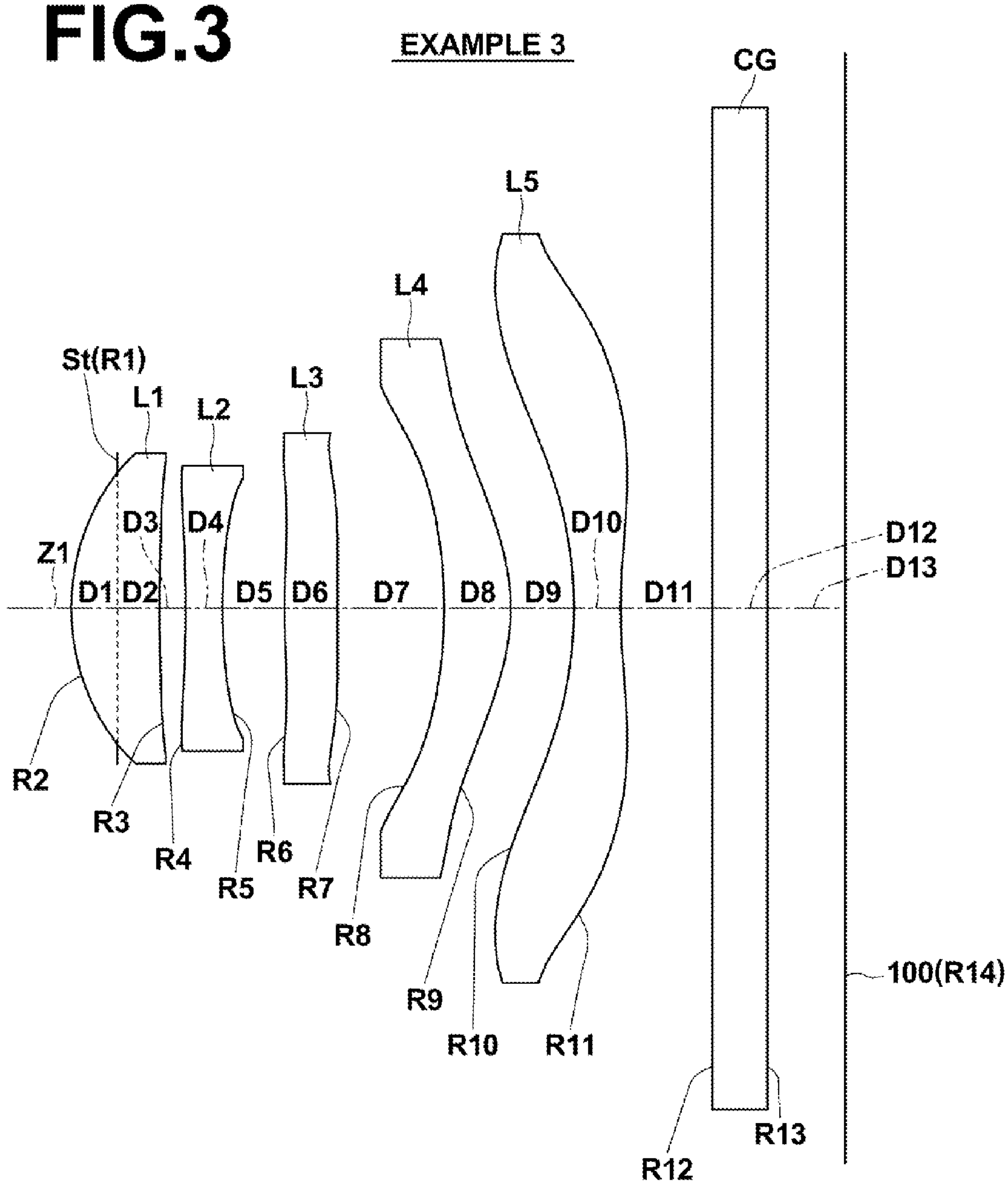

EXAMPLE 3
CG
L5
L4
St(R1)
L1
L2
L3
D3
D4
D10
D12
D13
Z1
D1
D2
D5
D6
D7
D8
D9
D11
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
100(R14)
R12
R13

FIG.4

EXAMPLE 4

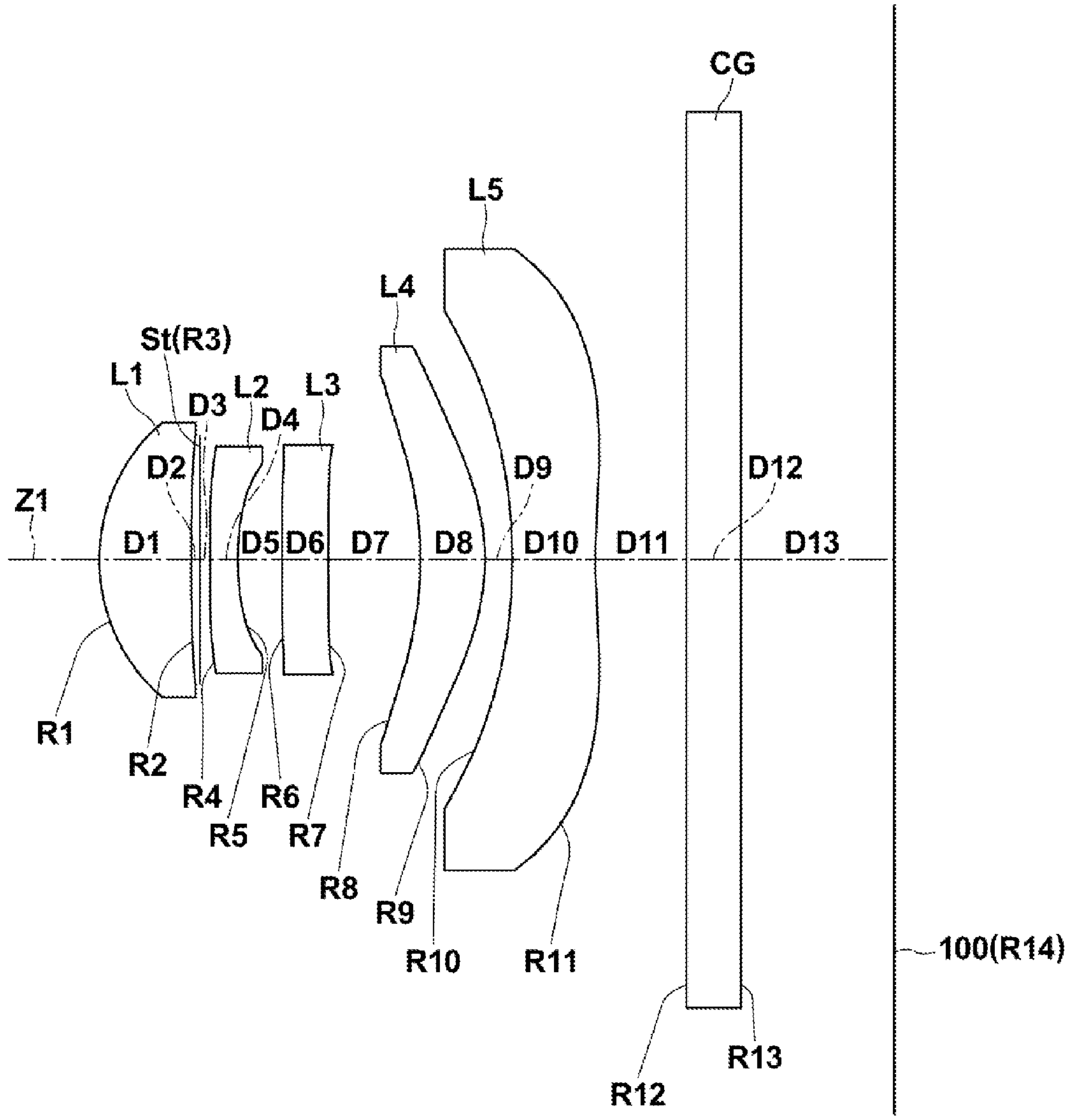


FIG.5

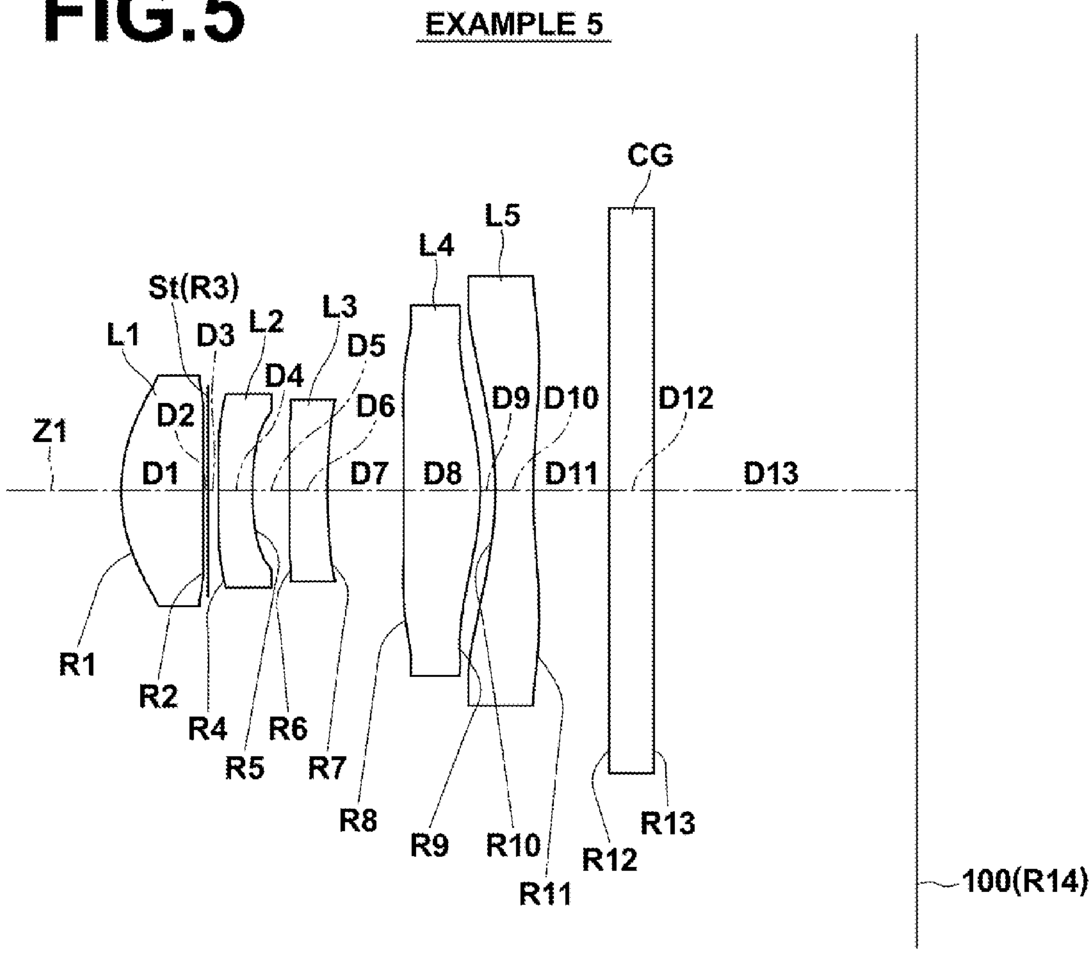

EXAMPLE 5
CG
L5
L4
St(R3)
L3
L1
D3
L2
D5
D4
D9
D10
D12
D2
D6
Z1
D1
D7
D8
D11
D13
R1
R2
R4
R6
R5
R7
R8
R9
R10
R13
R12
R11
100(R14)

FIG.6

EXAMPLE 6

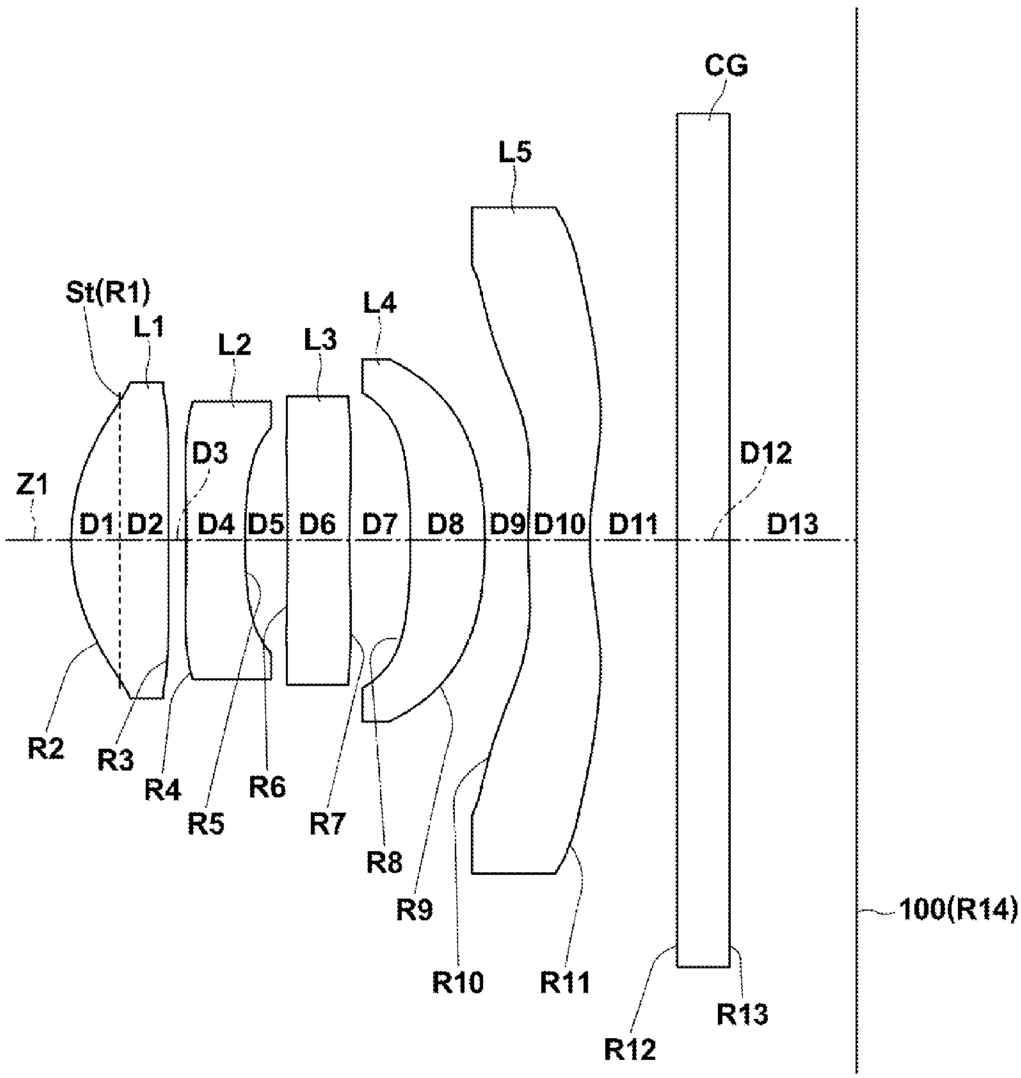


FIG.7

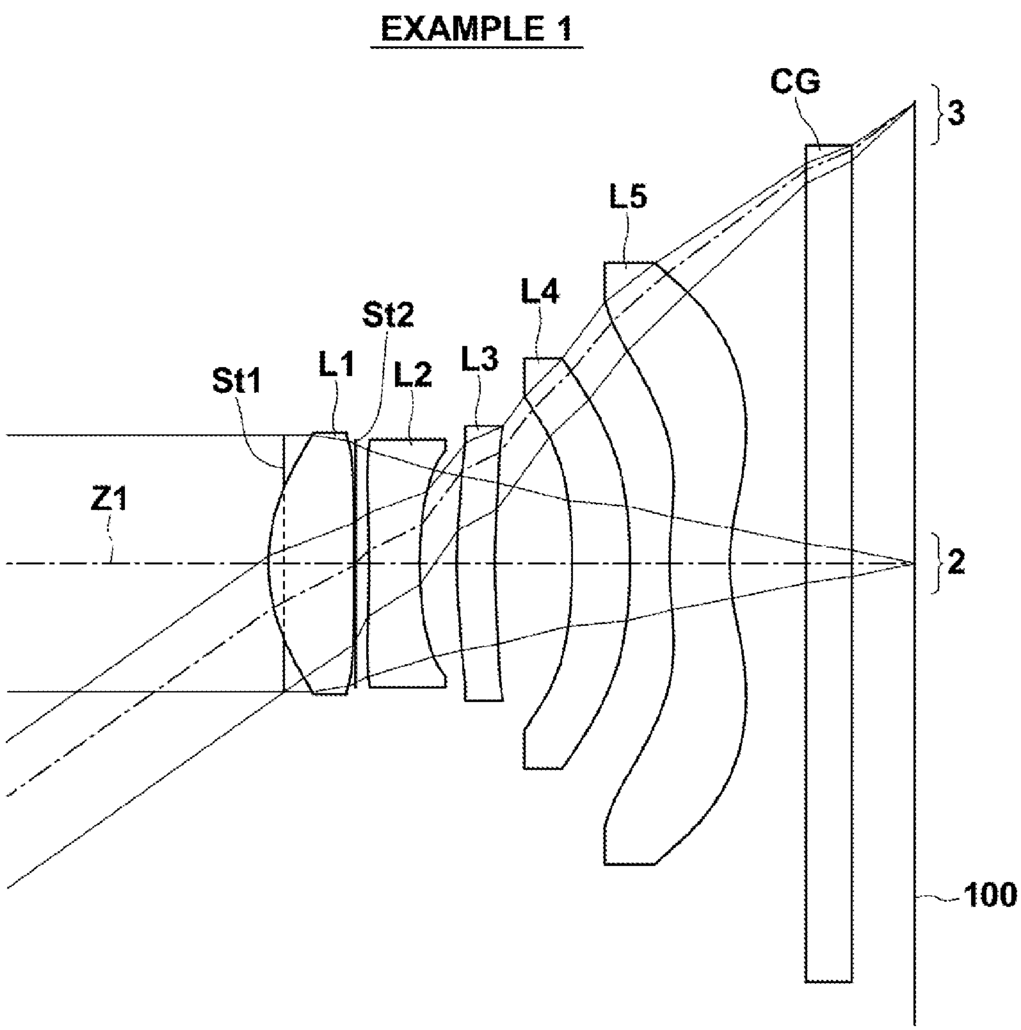


FIG.8

EXAMPLE 1

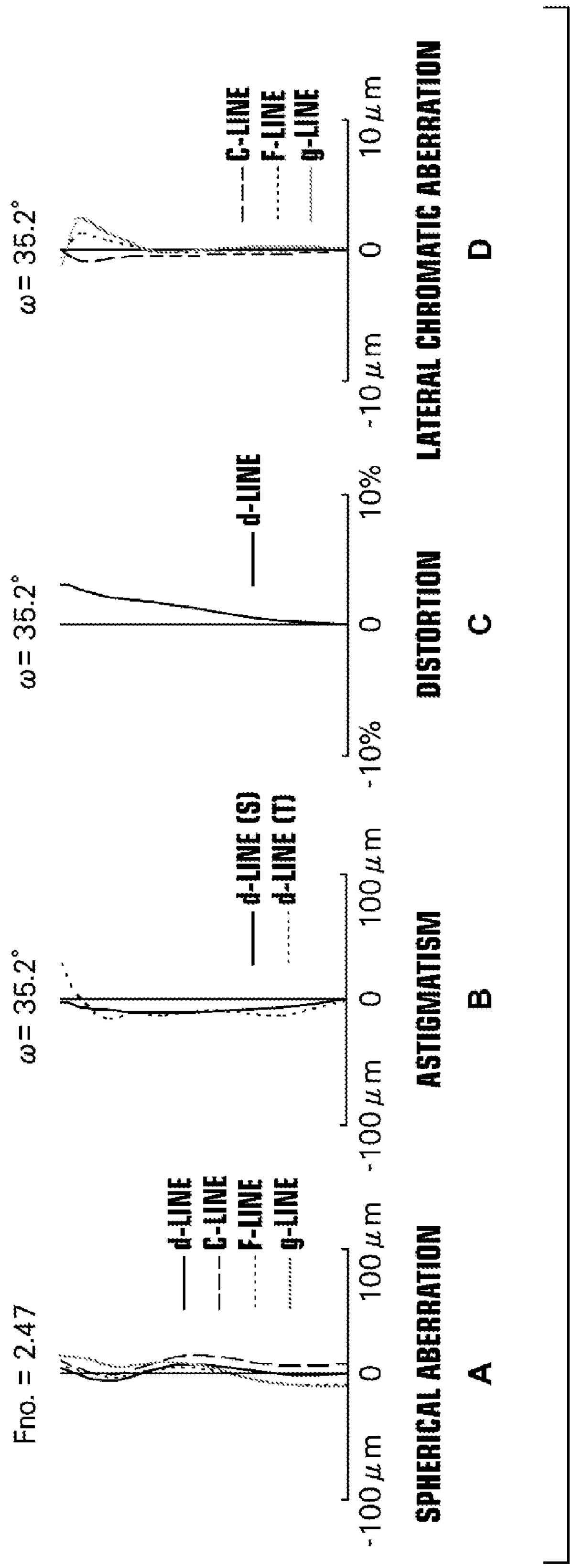


FIG.9

EXAMPLE 2

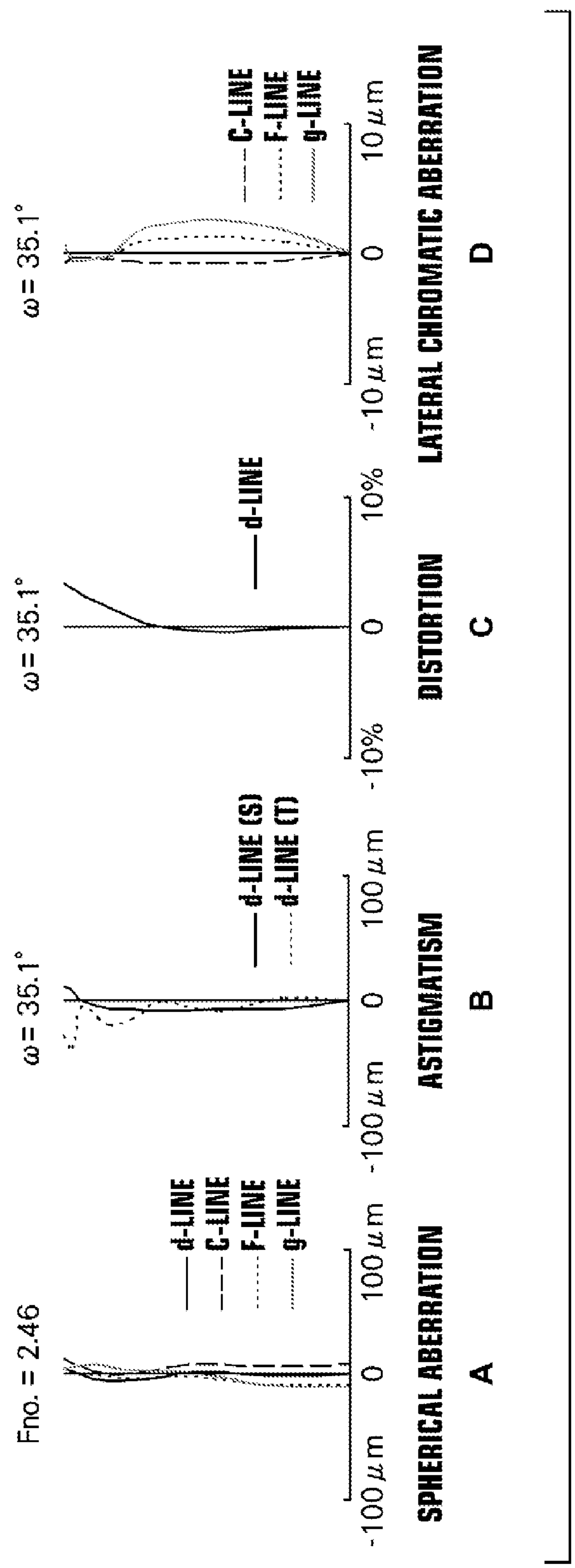


FIG.10

EXAMPLE 3

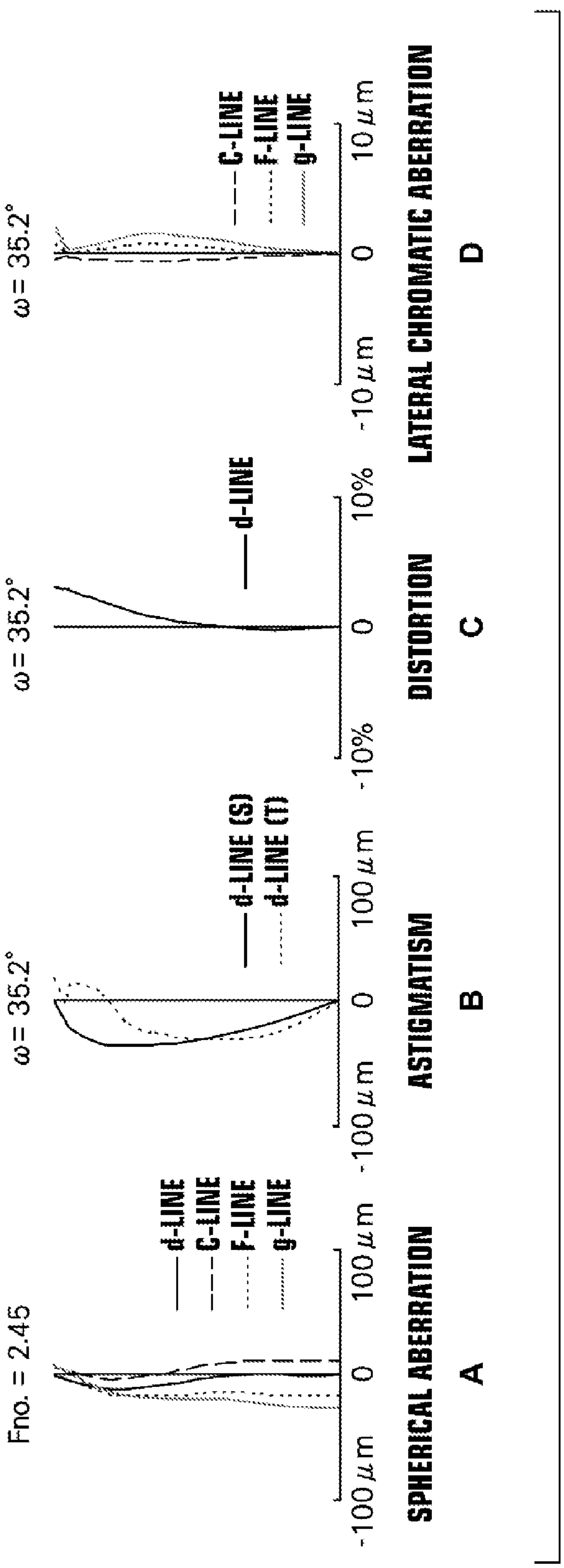


FIG.11

EXAMPLE 4

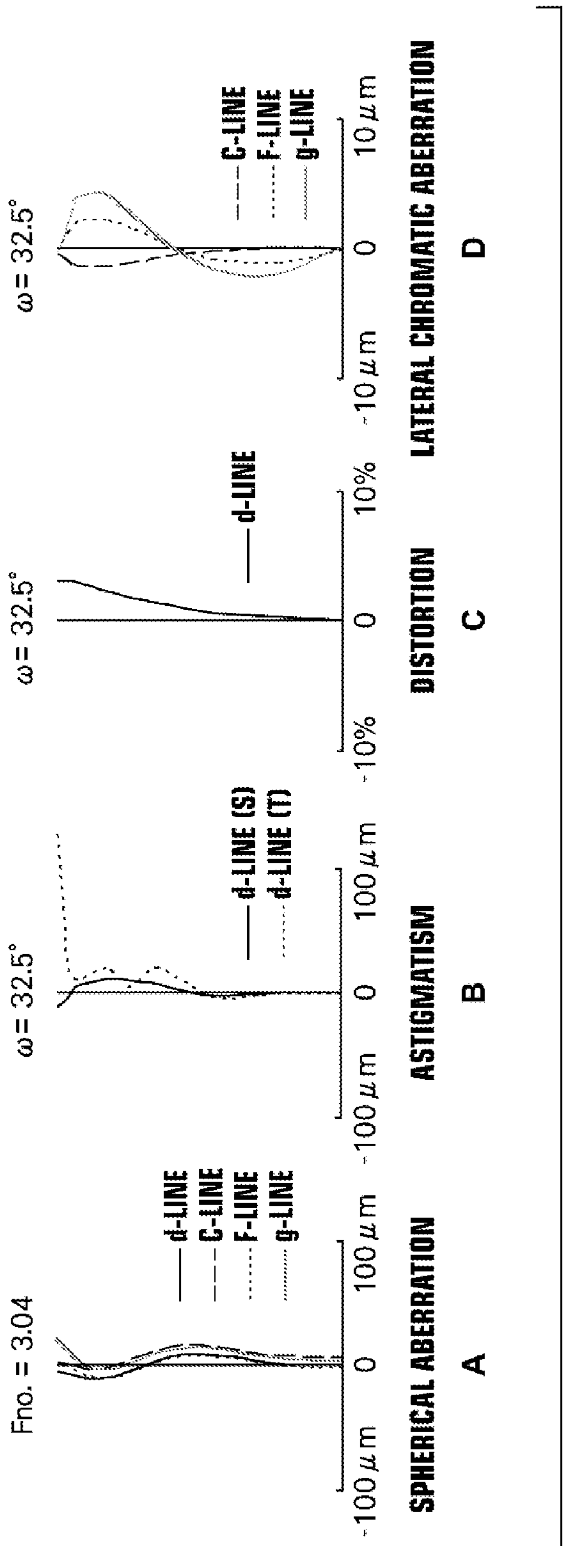


FIG.12

EXAMPLE 5

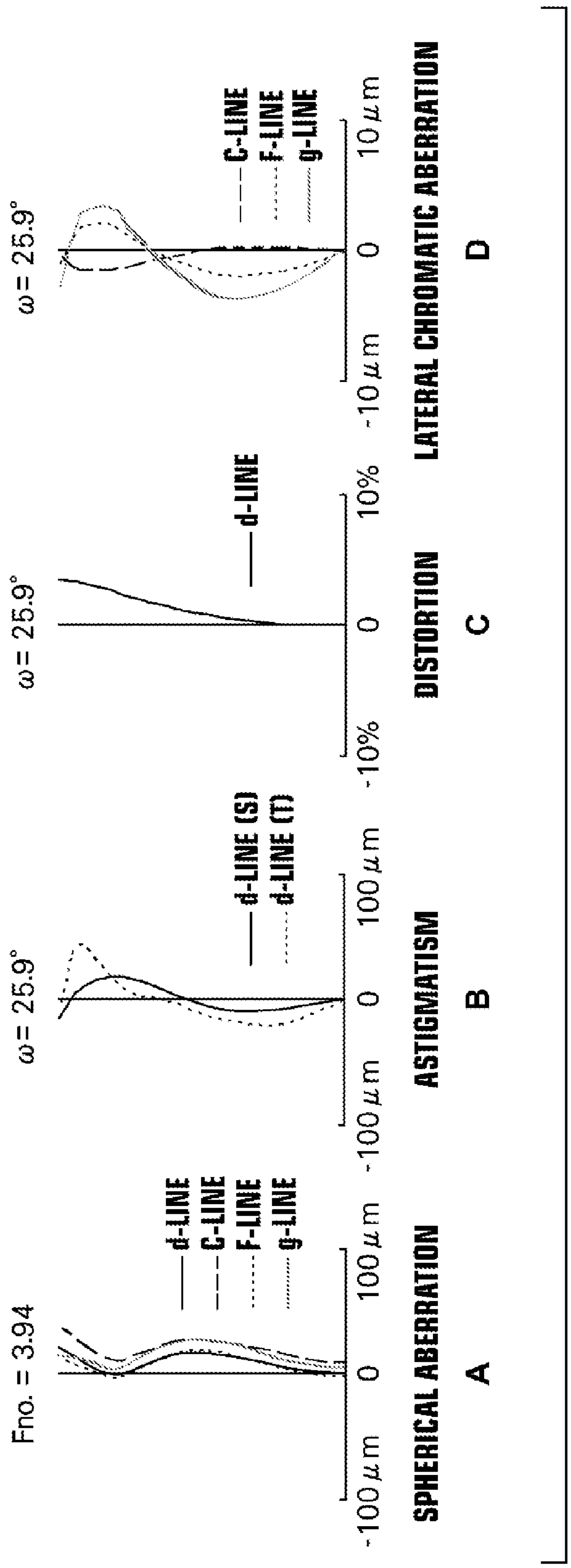
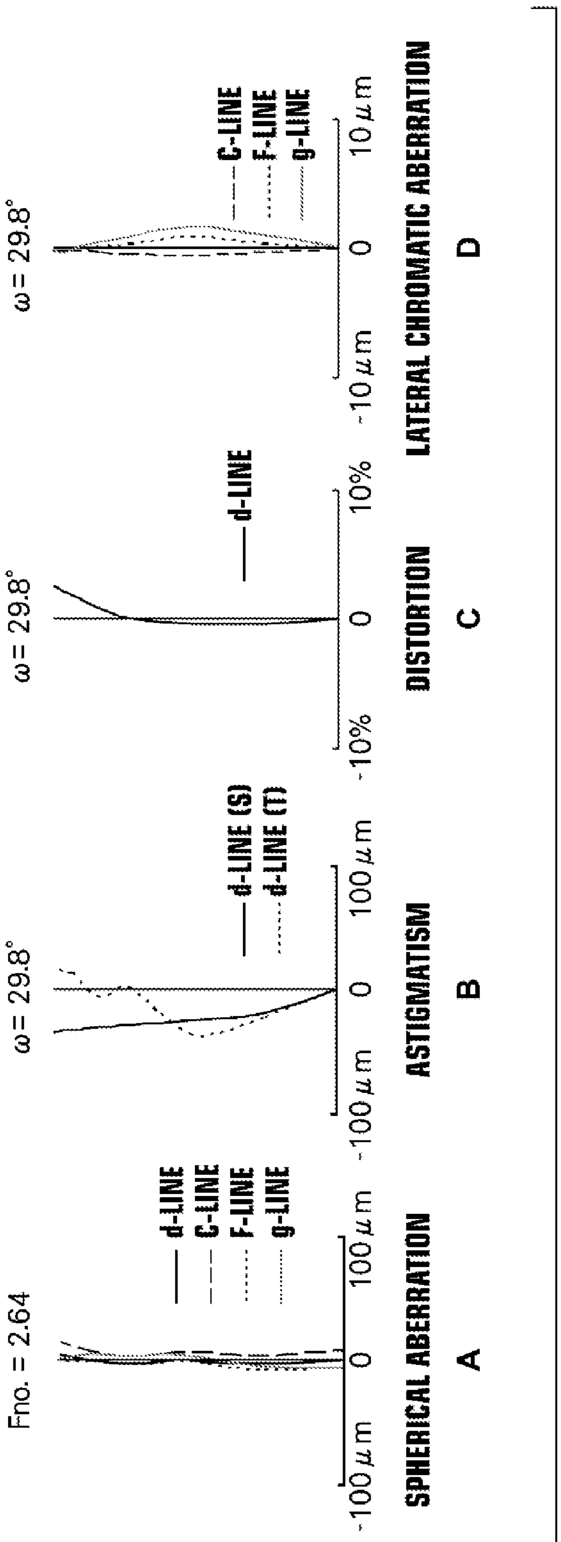


FIG.13

EXAMPLE 6



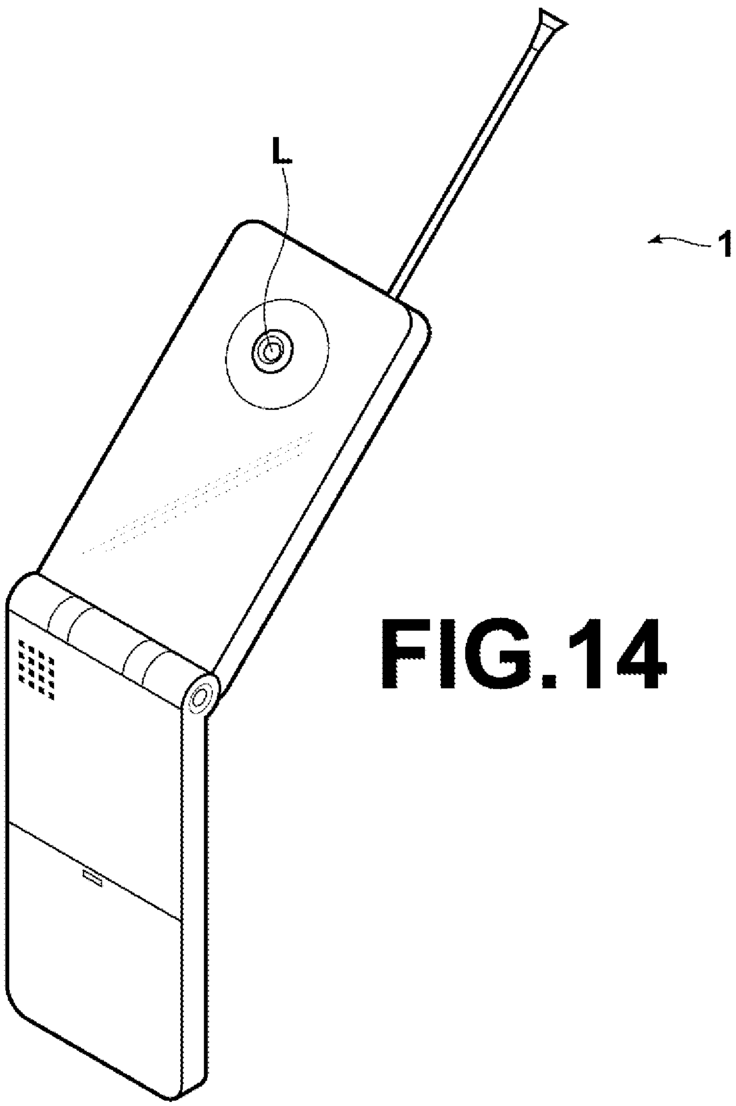


FIG.14

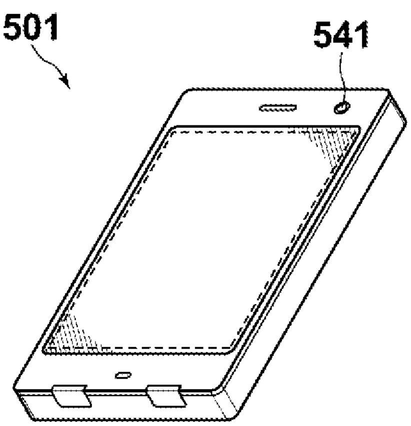


FIG.15

IMAGING LENS AND IMAGING APPARATUS INCLUDING THE IMAGING LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a fixed-focus imaging lens that forms an optical image of a subject on an imaging device, such as a charge coupled device (CCD) and a complementary metal oxide semiconductor (CMOS), and to an imaging apparatus, such as a digital still camera, a cellular phone with a camera, a mobile information terminal (PDA: Personal Digital Assistance), a smartphone, a tablet terminal, and a mobile game machine, on which the imaging lens is mounted to perform photography.

2. Description of the Related Art

As personal computers have become popular in homes, digital still cameras which are capable of inputting image information about photographed scenes, persons, and the like into the personal computers have spread rapidly. Further, a cellular phone, a smartphone, or a tablet terminal in which a camera module for inputting images is installed has been increasing. Such apparatus having an imaging function uses an imaging device, such as a CCD and a CMOS. Recently, because the imaging device has been miniaturized, there has been also a demand to miniaturize the whole of the imaging apparatus and an imaging lens mounted thereon. Further, since the number of pixels included in the imaging device has also been increasing, there has been a demand to enhance the resolution and performance of the imaging lens. For example, there has been a demand for performance corresponding to high resolution of 5 megapixels or higher, and preferably performance corresponding to high resolution of 8 megapixels or higher.

To satisfy such demands, it can be considered that the imaging lens is composed of five or six lenses, which are a relatively large number of lenses. For example, U.S. Pat. No. 8,310,768 (Patent Document 1) and U.S. Patent Application Publication No. 20130033765 (Patent Document 2) propose an imaging lens composed of five lenses. The imaging lens disclosed in Patent Documents 1 and 2 substantially consists of, in order from an object side, five lenses of a first lens that has a positive refractive power, a second lens that has a negative refractive power, a third lens that has a positive refractive power, a fourth lens that has a positive refractive power, and a fifth lens that has a negative refractive power.

SUMMARY OF THE INVENTION

In particular, for the imaging lenses used in apparatuses, of which the thickness has been decreased, such as a cellular phone, a smartphone or a tablet terminal, a demand to decrease the total length of the lens has been increased more and more. Hence, it is necessary to further decrease the total lengths of the imaging lenses disclosed in Patent Documents 1 and 2.

The present invention has been made in view of the above-mentioned circumstances and an object thereof is to provide an imaging lens capable of achieving high imaging performance in the range from the central angle of view to the peripheral angle of view while achieving a decrease in the total length thereof. Another object of the present invention is to provide an imaging apparatus capable of obtaining a photographed image with high resolution through the imaging lens which is mounted thereon.

The imaging lens of the present invention is an imaging lens substantially consisting of, in order from an object side, five lenses of:

a first lens that has a positive refractive power and has a meniscus shape which is convex toward the object side;

a second lens that has a biconcave shape;

a third lens that has a meniscus shape which is convex toward the object side;

a fourth lens that has a meniscus shape which is convex toward an image side; and

a fifth lens that has a negative refractive power and has at least one inflection point on an image side surface,

in which the following conditional expression (1) is satisfied:

$$1.4<f/f1<4 \quad (1),\text{ where}$$

f is a focal length of a whole system, and

f1 is a focal length of the first lens.

According to the imaging lens of the present invention, in the imaging lens which is composed of five lenses as a whole, a configuration of each lens element of the first to fifth lenses is optimized. Therefore, it is possible to achieve a lens system that has high resolution performance while decreasing the total length thereof.

In the imaging lens of the present invention, the expression "substantially consisting of five lenses" means that the imaging lens of the present invention may include not only the five lenses but also a lens which has substantially no refractive power, optical elements, such as a stop and a cover glass, which are not a lens, mechanism parts, such as a lens flange, a lens barrel, an imaging device and a hand shake blur correction mechanism, and the like. When the lens includes an aspheric surface, the reference sign of the surface shape and refractive power of the lens is considered in a paraxial region.

In the imaging lens of the present invention, by employing and satisfying the following desirable configuration, it is possible to make the optical performance thereof better.

In the imaging lens of the present invention, it is desirable that the fourth lens have a positive refractive power.

It is desirable that the imaging lens of the present invention further include an aperture stop that is disposed on the object side of an object side surface of the second lens.

It is desirable that the imaging lens of the present invention satisfy any of the following conditional expressions (1-1) to (10). It should be noted that, as a desirable mode, any one of the conditional expressions (1-1) to (10) may be satisfied, or an arbitrary combination thereof may be satisfied. However, regarding the conditional expression (7-1), when the composite refractive power of the first to third lenses is positive, it is desirable to satisfy the conditional expression (7-1).

$$1.5<f/f1<3.5 \quad (1\text{-}1),$$

$$-3<f/f2<-0.85 \quad (2),$$

$$-2.5<f/f2<-0.9 \quad (2\text{-}1),$$

$$0.78<f/f12<2.5 \quad (3),$$

$$0.8<f/f12<2 \quad (3\text{-}1),$$

$$-2<f/f345<0 \quad (4),$$

$$-1.5<f/f345<-0.05 \quad (4\text{-}1),$$

$$-0.5<f1/f3<0.4 \quad (5),$$

$$-0.4<f1/f3<0.2 \quad (5\text{-}1),$$

$$-1<(R3f-R3r)/(R3f+R3r)<1.2 \quad (6),$$

$$-0.6<(R3f-R3r)/(R3f+R3r)<1 \quad (6\text{-}1),$$

$$-4<f/f5<-0.2 \quad (7),$$

$$-3<f/f5<-0.4 \quad (7\text{-}1),$$

$$0.5<f\cdot\tan\omega/R5r<10 \quad (8),$$

$$0.7<f\cdot\tan\omega/R5r<3 \quad (8\text{-}1),$$

$$-0.9<f/f3<0.7 \quad (9), \text{ and}$$

$$0.05<D7/f<0.2 \quad (10), \text{ where}$$

f is a focal length of a whole system,

f1 is a focal length of the first lens,

f2 is a focal length of the second lens,

f3 is a focal length of the third lens,

f5 is a focal length of the fifth lens,

f12 is a composite focal length of the first lens and the second lens,

f345 is a composite focal length of the third to fifth lenses,

R3f is a paraxial radius of curvature of an object side surface of the third lens,

R3r is a paraxial radius of curvature of an image side surface of the third lens,

R5r is a paraxial radius of curvature of an image side surface of the fifth lens,

D7 is a spacing on an optical axis between the third lens and the fourth lens, and

ω is a half angle of view.

The imaging apparatus of the present invention includes the imaging lens of the present invention.

In the imaging apparatus of the present invention, imaging signals with high resolution can be obtained based on an optical image with high resolution obtained by the imaging lens of the present invention.

According to the imaging lens of the present invention, in the imaging lens which is composed of five lenses as a whole, a configuration of each lens element is optimized, and particularly the shapes of the first and fifth lenses are appropriately formed. Therefore, it is possible to achieve a lens system that has high resolution performance in the range from the central angle of view to the peripheral angle of view while decreasing the total length thereof.

Further, according to the imaging apparatus of the present invention, imaging signals based on an optical image formed by the imaging lens of the present invention, which has high imaging performance, are output. Therefore, it is possible to obtain a photographed image with high resolution.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a lens cross-sectional view illustrating a first configuration example of an imaging lens according to an embodiment of the present invention and corresponding to Example 1;

FIG. **2** is a lens cross-sectional view illustrating a second configuration example of an imaging lens according to an embodiment of the present invention and corresponding to Example 2;

FIG. **3** is a lens cross-sectional view illustrating a third configuration example of an imaging lens according to an embodiment of the present invention and corresponding to Example 3;

FIG. **4** is a lens cross-sectional view illustrating a fourth configuration example of an imaging lens according to an embodiment of the present invention and corresponding to Example 4;

FIG. **5** is a lens cross-sectional view illustrating a fifth configuration example of an imaging lens according to an embodiment of the present invention and corresponding to Example 5;

FIG. **6** is a lens cross-sectional view illustrating a sixth configuration example of an imaging lens according to an embodiment of the present invention and corresponding to Example 6;

FIG. **7** is a ray diagram of the imaging lens shown in FIG. **1**;

FIG. **8** is an aberration diagram illustrating various aberrations of an imaging lens according to Example 1 of the present invention, where Section A shows a spherical aberration, Section B shows astigmatism (curvature of field), Section C shows distortion, and Section D shows a lateral chromatic aberration;

FIG. **9** is an aberration diagram illustrating various aberrations of an imaging lens according to Example 2 of the present invention, where Section A shows a spherical aberration, Section B shows astigmatism (curvature of field), Section C shows distortion, and Section D shows a lateral chromatic aberration;

FIG. **10** is an aberration diagram illustrating various aberrations of an imaging lens according to Example 3 of the present invention, where Section A shows a spherical aberration, Section B shows astigmatism (curvature of field), Section C shows distortion, and Section D shows a lateral chromatic aberration;

FIG. **11** is an aberration diagram illustrating various aberrations of an imaging lens according to Example 4 of the present invention, where Section A shows a spherical aberration, Section B shows astigmatism (curvature of field), Section C shows distortion, and Section D shows a lateral chromatic aberration;

FIG. **12** is an aberration diagram illustrating various aberrations of an imaging lens according to Example 5 of the present invention, where Section A shows a spherical aberration, Section B shows astigmatism (curvature of field), Section C shows distortion, and Section D shows a lateral chromatic aberration;

FIG. **13** is an aberration diagram illustrating various aberrations of an imaging lens according to Example 6 of the present invention, where Section A shows a spherical aberration, Section B shows astigmatism (curvature of field), Section C shows distortion, and Section D shows a lateral chromatic aberration;

FIG. **14** is a diagram illustrating an imaging apparatus which is a cellular phone terminal including the imaging lens according to the present invention; and

FIG. **15** is a diagram illustrating an imaging apparatus which is a smartphone including the imaging lens according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, embodiments of the present invention will be described in detail with reference to the accompanying drawings.

FIG. **1** shows a first configuration example of an imaging lens according to a first embodiment of the present invention. The configuration example corresponds to a lens configuration of a first numerical value example (Table 1 and Table 2)

to be described later. Likewise, FIGS. **2** to **6** show cross sections of second to sixth configuration examples corresponding to the imaging lenses according to second to sixth embodiments to be described later. The second to sixth configuration examples correspond to lens configurations of the second to sixth numerical value examples (Tables 3 to 12) to be described later. In FIGS. **1** to **6**, the reference sign Ri represents a radius of curvature of i-th surface, where the number i is the sequential number that sequentially increases as it gets closer to an image side (an imaging side) when a surface of a lens element closest to an object side is regarded as a first surface. The reference sign Di represents an on-axis surface spacing between i-th surface and (i+1) th surface on an optical axis Z1. Since the respective configuration examples are basically similar in configuration, the following description will be given on the basis of the first configuration example of the imaging lens shown in FIG. **1**, and the configuration examples shown in FIGS. **2** to **6** will be also described as necessary. Further, FIG. **7** is an optical path diagram of the imaging lens L shown in FIG. **1**, and shows an optical path of rays **2** on the optical axis from an object point at the infinite distance and an optical path of rays **3** at the maximum angle of view.

An imaging lens L according to an embodiment of the present invention is appropriate to be used in various kinds of imaging apparatuses using imaging devices such as a CCD and a CMOS. Especially, the imaging lens L is appropriate to be used in relatively small-sized mobile terminal apparatus, for example, such as a digital still camera, a cellular phone with a camera, a smartphone, a tablet terminal, and a PDA. This imaging lens L includes, along the optical axis Z1, a first lens L1, a second lens L2, a third lens L3, a fourth lens L4, and a fifth lens L5 in this order from the object side.

FIG. **14** is a schematic diagram illustrating a cellular phone terminal, which is an imaging apparatus **1** according to an embodiment of the present invention. The imaging apparatus **1** according to the embodiment of the present invention includes imaging lens L according to the present embodiment and an imaging device **100** (refer to FIG. **1**), such as a CCD, which outputs imaging signals based on an optical image formed by the imaging lens L. The imaging device **100** is disposed at an image formation surface (image plane R14) of the imaging lens L.

FIG. **15** is a schematic diagram illustrating a smartphone which is an imaging apparatus **501** according to an embodiment of the present invention. The imaging apparatus **501** according to the embodiment of the present invention includes a camera unit **541** including the imaging lens L according to the present embodiment and the imaging device **100** (refer to FIG. **1**), such as a CCD, which outputs imaging signals based on an optical image formed by the imaging lens L. The imaging device **100** is disposed at the image formation surface (image plane R14) of the imaging lens L.

Various optical members CG may be disposed between the fifth lens L5 and the imaging device **100** based on the configuration of a camera on which the imaging lens is mounted. For example, a flat-plate-shaped optical member, such as a cover glass for protecting an imaging surface and an infrared-ray cut filter, may be disposed. In this case, for example, a flat-plate-shaped cover glass to which a coating having an effect of a filter, such as an infrared-ray cut filter and an ND filter, has been applied, or a material having the same effect may be used as the optical member CG.

Alternatively, an effect similar to the optical member CG may be given to the fifth lens L5 or the like by applying a coating to the fifth lens L5 or the like without using the optical member CG. Thereby, it is possible to reduce the number of components, and to reduce the total length.

Further, it is desirable that the imaging lens L includes an aperture stop St disposed on the object side of an object side surface of the second lens L2. Since the aperture stop St is disposed on the object side of the object side surface of the second lens L2 in such a manner, especially in a peripheral portion of an imaging area, it is possible to prevent an angle of incidence of rays, which pass through the optical system and are incident onto an imaging surface (imaging device), from becoming large. In order to further enhance this effect, it is more desirable that the aperture stop St be disposed on the object side of an object side surface of the first lens L1. Here, the expression "disposed on the object side of the object side surface of the second lens L2" means that the position of the aperture stop in the optical axis direction is the same as an intersection point between an on-axis marginal ray and the object side surface of the second lens L2 or located on the object side of the intersection point. Likewise, the expression "disposed on the object side of an object side surface of the first lens L1" means that the position of the aperture stop in the optical axis direction is the same as an intersection point between an on-axis marginal ray and the object side surface of the first lens L1 or located on the object side of the intersection point.

In the embodiments of the present invention, the imaging lenses of the third and sixth configuration examples (refer to FIGS. **3** and **6**) are configuration examples in which the aperture stop St is disposed on the object side of the object side surface of the first lens L1, and the imaging lenses of the first, second, fourth and fifth configuration examples (refer to FIGS. **1**, **2**, **4** and **5**) are configuration examples in which the aperture stop St is disposed on the object side of the object side surface of the second lens L2. It should be noted that the aperture stop St shown herein does not necessarily represent the size or shape thereof but shows the position thereof on the optical axis Z1.

When the aperture stop St is disposed on the object side of the object side surface of the second lens L2, a flare stop for suppressing a flare component or a ghost component may be further provided on the object side of the object side surface of the first lens L1. In the embodiments of the present invention, lenses as first and second configuration examples (FIGS. **1** and **2**) are configuration examples in which the flare stop is provided. It should be noted that, in FIGS. **1** and **2**, the flare stop is referenced by the reference sign St**1**, and the aperture stop is referenced by the reference sign St**2**. In this case, the aperture stop St**2** is a stop that restricts an F-number, and the flare stop St**1** is a stop that restricts rays at peripheral angles of view.

Furthermore, when the aperture stop St is disposed on the object side of the object side surface of the first lens L1 in the optical axis, it is desirable that the aperture stop St be disposed on the image side of a vertex of the surface of the first lens L1. When the aperture stop St is disposed on the image side of the vertex of the surface of the first lens L1 in such a manner, it is possible to reduce the total length of the imaging lens including the aperture stop St. In the above-mentioned embodiments, the aperture stop St is disposed on the image side of the vertex of the surface of the first lens L1. However, the invention is not limited to the embodiments, and the aperture stop St may be disposed on the object side of the vertex of the surface of the first lens L1. The arrangement, in which the aperture stop St is disposed on the object side of the vertex of the surface of the first lens L1, is slightly disadvantageous in terms of securing a peripheral light amount, compared with a case where the aperture stop St is disposed on the

image side of the vertex of the surface of the first lens L1. However, the arrangement can prevent an angle of incidence of rays, which pass through the optical system and are incident onto the imaging surface (imaging device), from becoming large in the peripheral portion of the imaging area in a more desirable manner.

As in the imaging lenses according to the first, second, fourth and fifth embodiments shown in FIGS. **1**, **2**, **4** and **5**, the aperture stop St (St**2**) may be disposed between the first lens L1 and the second lens L2 in the optical axis direction. In this case, it is possible to satisfactorily correct a curvature of field. When the aperture stop St is disposed between the first lens L1 and the second lens L2 in the optical axis direction, as compared with a case where the aperture stop St is disposed on the object side of the object side surface of the first lens L1 in the optical axis direction, this arrangement is disadvantageous in securing telecentricity, that is, making the principal rays parallel to such an extent that the principal rays are regarded as the optical axis (setting an incident angle thereof on the imaging surface such that the angle is approximate to zero). Thus, by applying an imaging device which is recently implemented as the development in the imaging device technology advances and in which deterioration in the light receiving efficiency and occurrence of color mixture due to increase of incident angle are more reduced than in the conventional imaging device, it is possible to achieve optimum optical performance.

In the imaging lens L, the first lens L1 has a positive refractive power in the vicinity of the optical axis, and has a meniscus shape which is convex toward the object side in the vicinity of the optical axis. As shown in the embodiments, by making the first lens L1, which is a lens closest to the object, have a positive refractive power and have a meniscus shape which is convex toward the object side in the vicinity of the optical axis, the position of the rear side principal point of the first lens L1 can be set to be close to the object, and thus it is possible to appropriately reduce the total length.

The second lens L2 has a biconcave shape in the vicinity of the optical axis. Thereby, it is possible to appropriately suppress occurrence of a high-order spherical aberration while satisfactorily correcting a chromatic aberration, and it is also possible to appropriately reduce the total length.

The third lens L3 has a meniscus shape which is convex toward the object side in the vicinity of the optical axis. Thereby, the position of the rear side principal point of the third lens L3 can be more appropriately set to be close to the object side, and thus it is possible to appropriately reduce the total length. As long as the third lens L3 has a meniscus shape which is convex toward the object side in the vicinity of the optical axis, it is possible to adopt a configuration in which the third lens L3 has a positive refractive power in the vicinity of the optical axis, and it is also possible to adopt a configuration in which the third lens L3 has a negative refractive power in the vicinity of the optical axis. As in the imaging lenses according to the first to third embodiments shown in FIGS. **1** to **3**, when the third lens L3 is configured to have a positive refractive power in the vicinity of the optical axis, it is possible to more appropriately reduce the total length. Further, as in the imaging lenses according to the fourth to sixth embodiments shown in FIGS. **4** to **6**, when the third lens L3 is configured to have a negative refractive power in the vicinity of the optical axis, it is possible to more satisfactorily correct a chromatic aberration.

The fourth lens L4 has a meniscus shape which is convex toward the image side in the vicinity of the optical axis. Thereby, it is possible to appropriately correct astigmatism. It is desirable that the fourth lens L4 have a positive refractive power in the vicinity of the optical axis. Thereby, especially at the medium angle of view, it is possible to prevent the angle of incidence of rays, which pass through the optical system and are incident onto the image formation surface (imaging device), from becoming large, and thus it is possible to satisfactorily correct a lateral chromatic aberration while appropriately reducing the total length.

The fifth lens L5 has a negative refractive power in the vicinity of the optical axis. A lens, which has a negative refractive power in the vicinity of the optical axis, is disposed to be closest to the image side of the imaging lens, whereby the imaging lens can be more appropriately made to have a telephoto type configuration as a whole, and thus it is possible to appropriately reduce the total length. In addition, since the fifth lens L5 has a negative refractive power in the vicinity of the optical axis, it is possible to appropriately correct a curvature of field. When the fifth lens L5 is concave toward the image side in the vicinity of the optical axis, it is possible to satisfactorily correct a curvature of field while more appropriately reducing the total length. In order to further enhance this effect, as shown in the first, second, and sixth embodiments, it is desirable that the fifth lens L5 have a meniscus shape which is concave toward the image side in the vicinity of the optical axis.

The fifth lens L5 has at least one inflection point within an effective diameter of the image side surface. The "inflection point" on the image side surface of the fifth lens L5 is defined as a point at which the shape of the image side surface of the fifth lens L5 changes from a convex shape to a concave shape (or from a concave shape to a convex shape) toward the image side. The inflection point can be disposed at an arbitrary position on the outside in a radial direction from the optical axis as long as the point is within the effective diameter of the image side surface of the fifth lens L5. As shown in the respective embodiments, by forming the image side surface of the fifth lens L5 in a shape in which the image side surface has at least one inflection point, especially in a peripheral portion of an image formation area, it is possible to prevent the angle of incidence of rays, which pass through the optical system and are incident onto the image formation surface (imaging device), from becoming large.

According to the imaging lens L, in the imaging lens which is composed of five lenses as a whole, a configuration of each lens element of the first to fifth lenses L1 to L5 is optimized. Therefore, it is possible to achieve a lens system that has high resolution performance while decreasing the total length thereof.

In the imaging lens L, in order to enhance the performance thereof, it is desirable that at least one surface of each lens of the first to fifth lenses L1 to L5 be formed as an aspheric surface.

Further, it is desirable that each of the lenses L1 to L5 constituting the imaging lens L be not formed as a cemented lens but a single lens. The reason is that, compared with a case where any of the lenses L1 to L5 is formed as a cemented lens, since the number of aspheric surfaces increases, a degree of freedom in design of each lens is enhanced, and it is possible to appropriately achieve reduction in the total length thereof.

Next, effects and advantages of the conditional expressions of the imaging lens L configured as described above will be described in detail.

First, it is desirable that the focal length f1 of the first lens L1 and the focal length f of the whole system satisfy the following conditional expression (1).

$$1.4<f/f1<4 \quad (1)$$

The conditional expression (1) defines a desirable numerical range of a ratio of the focal length f of the whole system to the focal length f1 of the first lens L1. By securing the refractive power of the first lens L1 such that f/f1 is greater than the lower limit of the conditional expression (1), the positive refractive power of the first lens L1 does not become excessively weak relative to the refractive power of the whole system, and thus it is possible to appropriately reduce the total length. By maintaining the refractive power of the first lens L1 such that f/f1 is less than the upper limit of the conditional expression (1), the positive refractive power of the first lens L1 does not become excessively strong relative to the refractive power of the whole system, and thus it is possible to satisfactorily correct especially a spherical aberration. In order to further enhance this effect, it is more desirable to satisfy the conditional expression (1-1), and it is even more desirable to satisfy the conditional expression (1-2).

$$1.5<f/f1<3.5 \tag{1-1}$$

$$1.6<f/f1<3 \tag{1-2}$$

Further, it is desirable that the focal length f2 of the second lens L2 and the focal length f of the whole system satisfy the following conditional expression (2).

$$-3<f/f2<-0.85 \tag{2}$$

The conditional expression (2) defines a desirable numerical range of a ratio of the focal length f of the whole system to the focal length f2 of the second lens L2. By maintaining the refractive power of the second lens L2 such that f/f2 is greater than the lower limit of the conditional expression (2), the refractive power of the second lens L2 does not become excessively strong relative to the refractive power of the whole system, and thus it is possible to appropriately reduce the total length. By securing the refractive power of the second lens L2 such that f/f2 is less than the upper limit of the conditional expression (2), the refractive power of the second lens L2 does not become excessively weak relative to the refractive power of the whole system, and thus it is possible to satisfactorily correct especially a longitudinal chromatic aberration. In order to further enhance this effect, it is more desirable to satisfy the conditional expression (2-1), and it is even more desirable to satisfy the conditional expression (2-2).

$$-2.5<f/f2<-0.9 \tag{2-1}$$

$$-2<f/f2<-0.95 \tag{2-2}$$

It is desirable that a composite focal length f12 of the first lens L1 and the second lens L2 and the focal length f of the whole system satisfy the following conditional expression (3).

$$0.78<f/f12<2.5 \tag{3}$$

The conditional expression (3) defines a desirable numerical range of a ratio of the focal length f of the whole system to the composite focal length f12 of the first lens L1 and the second lens L2. By securing the composite refractive power of the first lens L1 and the second lens L2 such that f/f12 is greater than the lower limit of the conditional expression (3), the composite refractive power of the first lens L1 and the second lens L2 does not become excessively weak relative to the refractive power of the whole system, and thus it is possible to appropriately reduce the total length. By maintaining the composite refractive power of the first lens L1 and the second lens L2 such that f/f12 is less than the upper limit of the conditional expression (3), the composite refractive power of the first lens L1 and the second lens L2 does not become excessively strong relative to the refractive power of the whole system, and thus it is possible to satisfactorily correct particularly a spherical aberration and a longitudinal chromatic aberration. In order to further enhance this effect, it is desirable to satisfy the conditional expression (3-1), and it is more desirable to satisfy the conditional expression (3-2).

$$0.8<f/f12<2 \tag{3-1}$$

$$0.9<f/f12<1.8 \tag{3-2}$$

Further, it is desirable that the composite focal length f345 of the third to fifth lenses L3 to L5 and the focal length f of the whole system satisfy the following conditional expression (4).

$$-2<f/f345<0 \tag{4}$$

The conditional expression (4) defines a desirable numerical range of a ratio of the focal length f of the whole system to the composite focal length f345 of the third to fifth lenses L3 to L5. By maintaining the composite refractive power of the third to fifth lenses L3 to L5 such that f/f345 is greater than the lower limit of the conditional expression (4), the composite refractive power of the third to fifth lenses L3 to L5 does not become excessively strong relative to the refractive power of the whole system, and thus, especially at the medium angle of view, it is possible to prevent the angle of incidence of rays, which pass through the optical system and are incident onto the image formation surface (imaging device), from becoming large. By securing the composite refractive power of the third to fifth lenses L3 to L5 such that f/f345 is less than the upper limit of the conditional expression (4), the composite refractive power of the third to fifth lenses L3 to L5 does not become excessively weak relative to the refractive power of the whole system, and thus it is possible to appropriately reduce the total length. In order to further enhance this effect, it is desirable to satisfy the conditional expression (4-1), and it is more desirable to satisfy the conditional expression (4-2).

$$-1.5<f/f345<-0.05 \tag{4-1}$$

$$-1.2<f/f345<-0.05 \tag{4-2}$$

Further, it is desirable that the focal length f1 of the first lens L1 and the focal length f3 of the third lens L3 satisfy the following conditional expression (5).

$$-0.5<f1/f3<0.4 \tag{5}$$

The conditional expression (5) defines a desirable numerical range of a ratio of the focal length f1 of the first lens L1 to the focal length f3 of the third lens L3. When the third lens L3 has a negative refractive power, by securing the refractive power of the third lens L3 relative to the refractive power of the first lens L1 such that f1/f3 is greater than the lower limit of the conditional expression (5), the negative refractive power of the third lens L3 does not become excessively strong relative to the refractive power of the first lens L1. As a result, it is possible to appropriately reduce the total length. When the third lens L3 has a positive refractive power, by securing the refractive power of the third lens L3 relative to the refractive power of the first lens L1 such that f1/f3 is less than the upper limit of the conditional expression (5), the positive refractive power of the third lens L3 does not become excessively strong relative to the refractive power of the first lens L1. As a result, it is possible to satisfactorily correct a spherical aberration. In order to further enhance this effect, it is more desirable to satisfy the conditional expression (5-1).

$$-0.4<f1/f3<0.2 \tag{5-1}$$

It is desirable that the paraxial radius of curvature R3f of the object side surface of the third lens L3 and the paraxial radius of curvature R3r of the image side surface of the third lens L3 satisfy the following conditional expression (6).

$$-1<(R3f-R3r)/(R3f+R3r)<1.2 \quad (6)$$

The conditional expression (6) defines each of a desirable numerical range of the paraxial radius of curvature R3f of the object side surface of the third lens L3 and a desirable numerical range of the paraxial radius of curvature R3r of the image side surface of the third lens L3. By setting the paraxial radius of curvature R3f of the object side surface of the third lens L3 and the paraxial radius of curvature R3r of the image side surface of the third lens L3 such that (R3f−R3r)/(R3f+R3r) is greater than the lower limit of the conditional expression (6), it is possible to appropriately reduce the total length. By setting the paraxial radius of curvature R3f of the object side surface of the third lens L3 and the paraxial radius of curvature R3r of the image side surface of the third lens L3 such that (R3f−R3r)/(R3f+R3r) is less than the upper limit of the conditional expression (6), it is possible to satisfactorily correct a spherical aberration. In order to further enhance this effect, it is more desirable to satisfy the following conditional expression (6-1).

$$-0.6<(R3f-R3r)/(R3f+R3r)<1 \quad (6\text{-}1)$$

Further, it is desirable that the focal length f5 of the fifth lens L5 and the focal length f of the whole system satisfy the following conditional expression (7).

$$-4<f/f5<-0.2 \quad (7)$$

The conditional expression (7) defines a desirable numerical range of a ratio of the focal length f of the whole system to the focal length f5 of the fifth lens L5. By maintaining the refractive power of the fifth lens L5 such that f/f5 is greater than the lower limit of the conditional expression (7), the refractive power of the fifth lens L5 does not become excessively strong relative to the positive refractive power of the whole system, and thus, especially at the medium angle of view, it is possible to prevent the angle of incidence of rays, which pass through the optical system and are incident onto the image formation surface (imaging device), from becoming large. By securing the refractive power of the fifth lens L5 such that f/f5 is less than the upper limit of the conditional expression (7), the refractive power of the fifth lens L5 does not become excessively weak relative to the refractive power of the whole system, and thus it is possible to appropriately reduce the total length while satisfactorily correcting a curvature of field. In order to further enhance this effect, when the composite refractive power of the first to third lenses L1 to L3 is positive, it is more desirable to satisfy the conditional expression (7-1).

$$-3<f/f5<-0.4 \quad (7\text{-}1)$$

Further, it is desirable that the focal length f of the whole system, the half angle of view ω, and the paraxial radius of curvature R5r of the image side surface of the fifth lens L5 satisfy the following conditional expression (8).

$$0.5<f\cdot\tan\omega/R5r<10 \quad (8)$$

The conditional expression (8) defines a desirable numerical range of a ratio of the paraxial image height (f·tan ω) to the paraxial radius of curvature R5r of the image side surface of the fifth lens L5. By setting the paraxial image height (f·tan ω) relative to the paraxial radius of curvature R5r of the image side surface of the fifth lens L5 such that f·tan ω/R5r is greater than the lower limit of the conditional expression (8), an absolute value of the paraxial radius of curvature R5r of the image side surface of the fifth lens L5, which is a surface of the imaging lens closest to the image side, does not become excessively large relative to the paraxial image height (f·tan ω), and thus, it is possible to sufficiently correct a curvature of field while reducing the total length. Further, by setting the paraxial image height (f·tan ω) relative to the paraxial radius of curvature R5r of the image side surface of the fifth lens L5 such that f·tan ω/R5r is less than the upper limit of the conditional expression (8), the absolute value of the paraxial radius of curvature R5r of the image side surface of the fifth lens L5, which is a surface of the imaging lens closest to the image side, does not become excessively small relative to the paraxial image height (f·tan ω), and thus, especially at the medium angle of view, it is possible to prevent the angle of incidence of rays, which pass through the optical system and are incident onto the image formation surface (imaging device), from becoming large. In order to further enhance this effect, it is desirable to satisfy the conditional expression (8-1).

$$0.7<f\cdot\tan\omega/R5r<3 \quad (8\text{-}1)$$

Further, it is desirable that the focal length f3 of the third lens L3 and the focal length f of the whole system satisfy the following conditional expression (9).

$$-0.9<f/f3<0.7 \quad (9)$$

The conditional expression (9) defines a desirable numerical range of a ratio of the focal length f of the whole system to the focal length f3 of the third lens L3. When the third lens L3 has a negative refractive power, by maintaining the refractive power of the third lens L3 such that f/f3 is greater than the lower limit of the conditional expression (9), the negative refractive power of the third lens L3 does not become excessively strong relative to the refractive power of the whole system, and thus it is possible to appropriately reduce the total length. When the third lens L3 has a positive refractive power, by securing the refractive power of the third lens L3 such that f/f3 is less than the upper limit of the conditional expression (9), the positive refractive power of the third lens L3 does not become excessively strong relative to the refractive power of the whole system, and thus it is possible to satisfactorily correct a spherical aberration. In order to further enhance this effect, it is more desirable to satisfy the conditional expression (9-1).

$$-0.4<f/f3<0.5 \quad (9\text{-}1)$$

Further, it is desirable that the spacing D7 on the optical axis between the third lens L3 and the fourth lens L4 and the focal length f of the whole system satisfy the following conditional expression (10).

$$0.05<D7/f<0.2 \quad (10)$$

The conditional expression (10) defines a desirable numerical range of a ratio of the spacing D7 on the optical axis between the third lens L3 and the fourth lens L4 to the focal length f of the whole system. By securing the spacing D7 on the optical axis between the third lens L3 and the fourth lens L4 relative to the focal length f of the whole system such that D7/f is greater than the lower limit of the conditional expression (10), it is possible to appropriately suppress distortion which tends to occur when the total length is reduced. By maintaining the spacing D7 on the optical axis between the third lens L3 and the fourth lens L4 relative to the focal length f of the whole system such that D7/f is less than the upper limit of the conditional expression (10), it is possible to satisfactorily correct astigmatism. In order to further enhance this effect, it is desirable to satisfy the conditional expression (10^{-1}).

$$0.07<D7/f<0.17 \quad (10\text{-}1)$$

Next, referring to FIGS. **2** to **6**, imaging lenses according to second to sixth embodiments of the present invention will be described in detail. In the imaging lenses according to the first to sixth embodiments shown in FIGS. **1** to **6**, all surfaces of the first to fifth lenses L1 to L5 are formed to be aspheric. As in the first embodiment, the imaging lenses according to the second to sixth embodiments of the present invention substantially consist of, in order from the object side, five lenses of: the first lens L1 that has a positive refractive power and has a meniscus shape which is convex toward the object side; the second lens L2 that has a biconcave shape; the third lens L3 that has a meniscus shape which is convex toward the object side; the fourth lens L4 that has a meniscus shape which is convex toward the image side; and the fifth lens L5 that has a negative refractive power and has at least one inflection point on an image side surface. Hence, in the following first to sixth embodiments, only the different specific configurations of the lenses constituting the respective lens groups will be described. Since the configurations which are common among the first to sixth embodiments respectively have the same effects, configurations and effects thereof will be described in order of the sequence numbers of the embodiments, and the configurations and effects common to the other embodiments will not be repeatedly described but will be omitted.

In the imaging lens L according to the second embodiment shown in FIG. **2**, the lens configurations of the first to fifth lenses L1 to L5 are common to the first embodiment. Therefore, according to the respective lens configurations, it is possible to obtain the same effects as the respective corresponding configurations of the first embodiment.

As in the third embodiment shown in FIG. **3**, the fifth lens L5 may be configured to have a biconcave shape, and the configurations of the first to fifth lenses L1 to L5 may be common to the configurations of the first embodiment except that the fifth lens L5 has a biconcave shape. By making the fifth lens L5 have a biconcave shape, it is possible to set a strong negative refractive power, and thus it is possible to appropriately reduce the total length. Further, in the third embodiment, according to the respective configurations of the first to fifth lenses L1 to L5 common to the first embodiment, it is possible to obtain the same effects as the respective corresponding configurations of the first embodiment.

As in the fourth embodiment shown in FIG. **4**, the third lens L3 may be configured to have a negative refractive power in the vicinity of the optical axis, and the configurations of the first to fifth lenses L1 to L5 may be common to the configurations of the third embodiment except that the third lens L3 has a negative refractive power in the vicinity of the optical axis. By making the third lens L3 have a negative refractive power in the vicinity of the optical axis, it is possible to satisfactorily correct a chromatic aberration. Further, in the fourth embodiment, according to the respective configurations of the first to fifth lenses L1 to L5 common to the third embodiment, it is possible to obtain the same effects as the respective corresponding configurations of the third embodiment.

In the imaging lens L according to the fifth embodiment shown in FIG. **5**, the lens configurations of the first to fifth lenses L1 to L5 are common to the fourth embodiment. Therefore, according to the respective lens configurations, it is possible to obtain the same effects as the respective corresponding configurations of the fourth embodiment.

As in the sixth embodiment shown in FIG. **6**, the fifth lens L5 may be configured to have a meniscus shape which is concave toward the image side, and the configurations of the first to fifth lenses L1 to L5 may be common to the configurations of the fourth embodiment except that the fifth lens L5 has a meniscus shape which is concave toward the image side. By making the fifth lens L5 have a meniscus shape which is concave toward the image side, it is possible to appropriately reduce the total length. Further, in the sixth embodiment, according to the respective configurations of the first to fifth lenses L1 to L5 common to the fourth embodiment, it is possible to obtain the same effects as the respective corresponding configurations of the fourth embodiment.

As described above, according to the imaging lens of the embodiment of the present invention, in the imaging lens which is composed of five lenses as a whole, the configurations of the respective lens elements are optimized. Therefore, it is possible to achieve a lens system having high resolution performance while reducing the total length.

By satisfying appropriately desirable conditions, it is possible to achieve higher imaging performance. Furthermore, according to the imaging apparatus of the embodiment, imaging signals based on an optical image, which is formed by the high-performance imaging lens according to the embodiment, are output. Therefore, it is possible to obtain a photographed image with high resolution in the range from the central angle of view to the peripheral angle of view.

Next, specific numerical examples of the imaging lens according to the embodiment of the present invention will be described. Hereinafter, a plurality of numerical examples will be described collectively.

Table 1 and Table 2, which will be given later, show specific lens data corresponding to the configuration of the imaging lens shown in FIG. **1**. Specifically, Table 1 shows basic lens data, and Table 2 shows data on aspheric surfaces. In the lens data shown in Table 1, the column of surface number Si shows the surface number of the i-th surface in the imaging lens of Example 1. The surface of the lens element closest to the object side is the first surface (the aperture stop St is the first), and surface numbers sequentially increase toward the image side. The column of the radius of curvature Ri shows values (mm) of the radius of curvature of i-th surface from the object side to correspond to the reference sign Ri in FIG. **1**. Likewise, the column of the on-axis surface spacing Di shows spaces (mm) on the optical axis between the i-th surface Si and the (1+1) th surface Si+1 on the optical axis from the object side. The column of Ndj shows values of the refractive index of the j-th optical element from the object side for the d-line (587.56 nm). The column of νdj shows values of the Abbe number of the j-th optical element from the object side for the d-line. It should be noted that, in each piece of lens data, as various data items, values of the focal length f of the whole system (mm), the back focal length Bf (mm), and the total lens length TL (mm) are respectively shown. In addition, the back focal length Bf indicates an air-converted value, and likewise, in the total lens length TL, the back focal length portion uses an air-converted value.

In the imaging lens according to Example 1, both surfaces of each of the first to fifth lenses L1 to L5 are aspheric. In the basic lens data shown in Table 1, the radii of curvature of these aspheric surfaces are represented as numerical values of the radius of curvature near the optical axis (paraxial radius of curvature).

Table 2 shows aspheric surface data in the imaging lens system according to Example 1. In the numerical values represented as the aspheric surface data, the reference sign "E" means that a numerical value following this is a "exponent" having a base of 10 and that this numerical value having a base of 10 and expressed by an exponential function is multiplied by a numerical value before the "E". For example, this means that "1.0E-02" is "1.0×10^{-2}".

As aspheric surface data, values of coefficients Ai and KA in the aspheric surface expression represented by the following expression (A) are shown. Specifically, Z represents the length (mm) of a perpendicular from a point on an aspheric surface at height h from an optical axis to a plane that contacts with the vertex of the aspheric surface (the plane perpendicular to the optical axis).

$$Z=C\cdot h^2/\{1+(1-KA\cdot C^2\cdot h^2)^{1/2}\}+\Sigma Ai\cdot h^i \quad \text{(A)}$$

Here,

Z is a depth of the aspheric surface (mm),

h is a distance (height) from the optical axis to the lens surface (mm),

C is a paraxial curvature=1/R

(R: a paraxial radius of curvature),

Ai is an i-th order aspheric surface coefficient (i is an integer equal to or greater than 3), and

KA is an aspheric surface coefficient.

As in the imaging lens according to the above-mentioned Example 1, Tables 3 to 12 show specific lens data as Examples 2 to 6, corresponding to the configuration of the imaging lenses shown in FIGS. **2** to **6**. In the imaging lenses according to Examples 1 to 6, both surfaces of each of the first to fifth lenses L1 to L5 are aspheric.

In Example 1, a flare stop having a diameter of 1.675 mm is disposed at a position of 0.101 mm from the vertex of the surface of the first lens L1 to the image side, and in Example 2, a flare stop having a diameter of 1.670 mm is disposed at a position of 0.101 ram from the vertex of the surface of the first lens L1 to the image side. But the descriptions of these flare stops are omitted in Tables 1 and 3. FIG. **8**, Section A to Section D show a spherical aberration, astigmatism (curvature of field), distortion (a distortion aberration), and a lateral chromatic aberration (a chromatic aberration of magnification) in the imaging lens of Example 1, respectively. Each aberration diagram illustrating a spherical aberration, astigmatism (curvature of field), and distortion (a distortion aberration) shows an aberration for the d-line (a wavelength of 587.56 nm) as a reference wavelength. The diagram of a spherical aberration diagram and the diagram of a lateral chromatic aberration diagram show also aberrations for the F-line (a wavelength of 486.1 nm) and the C—line (a wavelength of 656.27 nm). The diagram of a spherical aberration also shows an aberration for the g-line (a wavelength of 435.83 nm). In the diagram of astigmatism, the solid line indicates an aberration in the sagittal direction (5), and the broken line indicates an aberration in the tangential direction (T). Fno. indicates an F-number, and ω indicates a half angle of view.

Likewise, FIG. **9**, Section A to D to FIG. **13**, Section A to D show various aberrations of the imaging lenses of Examples 2 to 6.

Table 13 collectively shows values of the conditional expressions (1) and (10) of Examples 1 to 6 according to the present invention.

As can be seen from the above-mentioned numerical value data and aberration diagrams, in each example, high imaging performance is achieved while the total length is reduced.

The imaging lens of the present invention is not limited to the above-mentioned embodiments and examples, and may be modified to various forms. For example, the values of the radius of curvature, the on-axis surface spacing, the refractive index, the Abbe number, the aspheric surface coefficient, and the like of the lens elements are not limited to the values shown in the numerical examples, and may have different values.

Further, in the description of each of all the examples, it is a premise that the imaging lens is used with fixed focus, but it may be possible to adopt a configuration in which focus is adjustable. For example, the imaging lens may be configured in such a manner that autofocusing is possible by extending the whole lens system or by moving some lenses on the optical axis.

TABLE 1

EXAMPLE 1
f = 4.126, Bf = 1.111, TL = 4.137

Si	Ri	Di	ndj	νdj
*1	1.23831	0.557	1.54488	54.87
*2	93.70148	0.015		
3 (APERTURE STOP)	∞	0.085		
*4	−12.66265	0.334	1.63351	23.63
*5	2.60879	0.243		
*6	3.15915	0.253	1.63351	23.63
*7	4.55163	0.506		
*8	−3.56285	0.379	1.63351	23.63
*9	−3.58353	0.258		
*10	1.98236	0.396	1.54488	54.87
*11	1.23910	0.500		
12	∞	0.300	1.51633	64.14
13	∞	0.413		
14	∞			

*ASPHERIC SURFACE

TABLE 2

EXAMPLE 1 - ASPHERIC SURFACE DATA

SURFACE NUMBER	KA	A4	A6	A8
1	9.7589122E−01	−2.6729118E−02	4.7204449E−02	−2.6218167E−01
2	1.0000090E+00	−7.9154953E−02	8.3384460E−02	−6.1197888E−03
3	−1.6800000E+00	−3.8300234E−02	3.7458150E−01	−2.7551593E−01
4	3.1182039E+00	−7.3707562E−02	1.2126243E+00	−4.9458531E+00
5	6.9999076E−01	−2.6329653E−01	2.4873169E−01	6.8422800E−02
6	1.0000249E+00	−1.9056021E−01	1.2088188E−01	7.8189995E−02
7	−2.1000000E+01	−7.2840681E−02	−3.3284653E−01	5.2042516E−01
8	−2.8556198E+00	−1.2163394E−01	1.7522262E−02	−1.0676210E−02
9	−1.4000005E+01	−4.3055564E−01	2.7976405E−01	−9.4994461E−02
10	−5.9077860E+00	−2.7520458E−01	2.0923136E−01	−1.1952221E−01

TABLE 2-continued

EXAMPLE 1 - ASPHERIC SURFACE DATA				
	A10	A12	A14	A16
1	4.0997871E−01	−4.5226437E−01	1.0665075E−01	−8.1871346E−02
2	−2.0357974E−01	−9.6694982E−01	2.1915571E+00	−1.2401354E+00
3	−3.8447870E−01	−3.1121039E−01	2.3020800E+00	−1.6056084E+00
4	1.7803254E+01	−3.9765240E+01	4.8323265E+01	−2.3566996E+01
5	4.9267886E−01	−2.4199414E+00	3.4571789E+00	−1.8021267E+00
6	1.4186946E−01	−2.2779898E−01	−1.5644448E−02	4.4672840E−02
7	−4.7544883E−01	2.5326186E−01	−1.5953212E−02	−2.5450777E−02
8	3.2819033E−02	−8.8256572E−03	−7.6808797E−03	3.0337699E−03
9	1.2737276E−02	1.7450700E−03	−6.1232629E−04	3.3350877E−05
10	4.5143417E−02	−1.0711328E−02	1.3898779E−03	−7.1397774E−05

TABLE 3

EXAMPLE 2 f = 4.119, Bf = 1.069, TL = 4.120				
Si	Ri	Di	ndj	νdj
*1	1.23597	0.557	1.54488	54.87
*2	15.97054	0.020		
3 (APERTURE STOP)	∞	0.081		
*4	−19.29047	0.334	1.63351	23.63
*5	3.10552	0.243		
*6	2.53139	0.265	1.54488	54.87
*7	2.70709	0.506		
*8	−3.97938	0.417	1.63351	23.63
*9	−2.24497	0.258		
*10	5.09366	0.370	1.63351	23.63
*11	1.57691	0.500		
12	∞	0.300	1.51633	64.14
13	∞	0.372		
14	∞			

*ASPHERIC SURFACE

TABLE 5

EXAMPLE 3 f = 4.117, Bf = 1.123, TL = 4.117				
Si	Ri	Di	ndj	νdj
1 (APERTURE STOP)	∞	−0.252		
*2	1.21258	0.482	1.54488	54.87
*3	11.57312	0.141		
*4	−7.67379	0.202	1.63351	23.63
*5	3.45544	0.338		
*6	5.09875	0.287	1.63351	23.63
*7	14.62892	0.582		
*8	−2.51969	0.364	1.54488	54.87
*9	−1.10708	0.345		
*10	−2.07885	0.253	1.54488	54.87
*11	2.90776	0.500		
12	∞	0.300	1.51633	64.14
13	∞	0.425		
14	∞			

*ASPHERIC SURFACE

TABLE 4

EXAMPLE 2 - ASPHERIC SURFACE DATA				
SURFACE NUMBER	KA	A4	A6	A8
1	−6.9000900E−01	7.8401227E−02	4.8724169E−02	−3.1032450E−01
2	1.0000000E+00	−1.4179856E−01	1.2622836E−01	−3.1360196E−02
3	1.0000000E+01	−7.7610199E−02	4.1593603E−01	−1.7738968E−01
4	3.1182039E+00	−3.5937525E−02	9.8686897E−01	−3.2805080E+00
5	3.1872442E−01	−2.7915128E−01	2.8423559E−01	−2.1820589E−01
6	−5.0999884E−01	−1.9620120E−01	1.1264694E−01	−3.2207096E−01
7	−8.8745315E−01	−7.2840681E−02	−6.8446726E−01	2.6980741E+00
8	−2.3946942E+00	−2.3349899E−01	8.5626683E−02	−8.4780380E−02
9	−1.0079967E+01	−7.6948035E−01	7.1798466E−01	−2.9903150E−01
10	−1.3546000E+01	−3.4848072E−01	2.9750460E−01	−1.5469280E−01
	A10	A12	A14	A16
1	7.3975458E−01	−1.2853745E+00	1.0201759E+00	−4.1573183E−01
2	−3.1147565E−01	−2.5924164E−01	1.1354658E+00	−7.4361120E−01
3	−7.7126641E−01	9.2770917E−01	5.6561007E−01	−8.0673585E−01
4	1.1724933E+01	−2.7522413E+01	3.6438963E+01	−1.9556633E+01
5	6.4639121E−01	−1.6044352E+00	2.2177373E+00	−1.1204967E+00
6	8.7809423E−01	−1.2333009E+00	8.1561032E−01	−1.8182400E−01
7	−8.5699151E+00	1.3930093E+01	−1.1707336E+01	3.6414691E+00
8	1.8481830E−02	−7.3019643E−02	6.5021917E−02	−6.0493130E−03
9	5.3075607E−02	1.4586291E−03	−1.9559157E−03	2.1244648E−04
10	5.0295407E−02	−9.7601077E−03	1.0070371E−03	−4.1856063E−05

TABLE 6

EXAMPLE 3 - ASPHERIC SURFACE DATA

SURFACE NUMBER	KA	A4	A6	A8
1	−5.9868050E+00	4.8641128E−01	−7.9546902E−01	2.1017252E+00
2	1.9240955E+00	−5.3853512E−02	2.1154063E−01	−4.4017448E−01
3	1.0921760E+01	−9.5725484E−02	7.5943447E−01	−1.9145869E+00
4	4.2702877E+00	−7.3659102E−02	7.7800384E−01	−1.3378460E+00
5	−3.0446805E−01	−2.3909795E−01	3.8056203E−02	−5.1291279E−02
6	−4.1652815E+00	−2.0189182E−01	1.5477070E−01	−8.7156700E−01
7	1.5660356E−01	5.7683409E−02	−3.0103142E−01	4.8387321E−01
8	−2.5416033E+00	1.0901372E−01	−2.8841662E−01	4.5116212E−01
9	−2.8886199E+01	−2.1705115E−01	1.5308753E−01	−3.9562058E−02
10	−9.1851222E+00	−2.2493967E−01	1.6877855E−01	−9.7203848E−02

	A10	A12	A14	A16
1	−4.6930095E+00	7.3788098E+00	−6.6387072E+00	2.5968201E+00
2	7.2411728E−01	−5.0309707E−01	−2.0972869E−01	4.1332784E−01
3	3.6385814E+00	−4.9896476E+00	4.2590990E+00	−1.6942132E+00
4	4.0930579E−01	5.4769361E+00	−1.1317295E+01	7.5185167E+00
5	5.3246530E−01	−1.2087019E+00	2.1064446E+00	−1.3514237E+00
6	2.7793661E+00	−4.6106123E+00	4.3246333E+00	−1.6422211E+00
7	−5.4851430E−01	3.6013932E−01	−9.6281745E−02	3.4936818E−03
8	−3.2780850E−01	1.2031213E−01	−2.1115167E−02	1.2566134E−03
9	−6.4447571E−05	2.4915794E−03	−5.5626637E−04	4.0995922E−05
10	3.7535798E−02	−9.2150833E−03	1.2851713E−03	−7.5129992E−05

TABLE 7

EXAMPLE 4
f = 4.555, Bf = 1.538, TL = 4.260

Si	Ri	Di	ndj	νdj
*1	0.99476	0.506	1.54488	54.87
*2	253.01381	0.046		
3 (APERTURE STOP)	∞	0.056		
*4	−22.24707	0.152	1.63351	23.63
*5	1.69768	0.243		
*6	253.00000	0.253	1.63351	23.63
*7	39.05374	0.506		

TABLE 7-continued

EXAMPLE 4
f = 4.555, Bf = 1.538, TL = 4.260

Si	Ri	Di	ndj	νdj
*8	−1.90297	0.354	1.63351	23.63
*9	−1.16022	0.151		
*10	−3.16206	0.455	1.54488	54.87
*11	3.61431	0.500		
12	∞	0.300	1.51633	64.14
13	∞	0.840		
14	∞			

*ASPHERIC SURFACE

TABLE 8

EXAMPLE 4 - ASPHERIC SURFACE DATA

SURFACE NUMBER	KA	A4	A6	A8
1	1.1921937E+00	−2.8552244E−02	1.9464672E−02	−1.7622814E−01
2	−7.2205120E+00	1.0009125E−01	5.6965587E−02	−1.2128920E−04
3	−1.6800098E+00	4.3862266E−01	−2.5955621E−01	−3.0871421E−01
4	3.1182039E+00	4.9953409E−01	7.4979015E−01	−4.0780165E+00
5	−1.6495744E+01	−7.5670799E−04	4.6703185E−01	6.5512652E−03
6	9.9999036E−01	2.7502524E−02	2.3242844E−01	−7.5662102E−02
7	−6.1085232E+00	−7.2840681E−02	−6.1939901E−02	4.0213149E−01
8	−1.9317843E+00	2.9226488E−03	1.6279485E−02	−1.1936707E−02
9	−1.4000001E+01	−1.4394163E−01	1.2958519E−01	−6.9903475E−02
10	−1.3546000E+01	−2.3244698E−01	1.8331804E−01	−1.1223612E−01

	A10	A12	A14	A16
1	4.3011057E−01	−4.4272734E−01	9.7079058E−02	−6.1193103E−02
2	−1.7377307E−01	−9.7305688E−01	2.2005578E+00	−1.2311427E+00
3	−4.2662287E−01	−2.3413149E−01	2.5428004E+00	−1.9963875E+00
4	1.8205811E+01	−3.8842459E+01	6.3021364E+01	−5.0226037E+01
5	8.6310550E−01	−8.0002749E−01	3.6125413E+00	−1.5876512E+01

TABLE 8-continued

EXAMPLE 4 - ASPHERIC SURFACE DATA				
6	5.4526971E−02	−6.2891755E−02	2.2916270E−01	−1.9122565E−01
7	−4.7056467E−01	2.4130912E−01	−2.7435913E−02	−2.7992163E−02
8	2.7648276E−02	−8.7177546E−03	−7.5782951E−03	1.4110223E−03
9	1.3115167E−02	1.8723448E−03	−5.6945481E−04	−2.7551420E−06
10	4.4224273E−02	−1.0817291E−02	1.3978168E−03	−7.0081151E−05

TABLE 9

EXAMPLE 5
f = 5.956, Bf = 2.438, TL = 5.171

Si	Ri	Di	ndj	νdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	0.506	1.63351	23.63
*9	−1.70702	0.100		
*10	−2.17464	0.253	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

*ASPHERIC SURFACE

TABLE 11

EXAMPLE 6
f = 4.428, Bf = 1.424, TL = 4.387

Si	Ri	Di	ndj	νdj
1 (APERTURE STOP)	∞	−0.278		
*2	1.17174	0.557	1.54488	54.87
*3	101.21828	0.101		
*4	−8.52605	0.334	1.63351	23.63
*5	3.10246	0.243		
*6	253.12530	0.354	1.54488	54.87
*7	7.08468	0.350		
*8	−4.62732	0.427	1.63351	23.63
*9	−2.28837	0.246		
*10	2.81503	0.351	1.63351	23.63
*11	1.45940	0.500		
12	∞	0.300	1.51633	64.14
13	∞	0.726		
14	∞			

*ASPHERIC SURFACE

TABLE 10

EXAMPLE 5 - ASPHERIC SURFACE DATA

SURFACE NUMBER	KA	A4	A6	A8
1	6.9377302E−01	−8.6315370E−03	−2.9322827E−03	−2.8236519E−01
2	1.0000090E+00	1.0299728E−02	−3.3338883E−02	−3.5854402E−01
3	9.8073731E+00	4.1860316E−01	2.4161475E−01	−7.6083670E−01
4	3.1182039E+00	4.6995645E−01	1.5149631E+00	−2.7101440E+00
5	6.1881621E−01	−1.9777356E−01	1.5104859E+00	−1.5044509E+00
6	9.9999979E−01	−1.3815608E−01	8.2457564E−01	−4.9516542E−01
7	3.2258104E−01	−7.2840681E−02	1.5663313E−01	9.8367802E−02
8	−2.6292010E+00	1.1379689E−01	−1.7291781E−02	2.9845655E−02
9	−1.4000002E+01	−4.4092972E−02	9.9278653E−02	−7.7922450E−02
10	1.3000586E−01	−1.8315230E−01	1.3758774E−01	−9.0542240E−02

	A10	A12	A14	A16
1	3.6582042E−01	−4.2487703E−01	−2.2631039E−01	−2.0344291E−02
2	−2.1599412E−01	−4.4977846E−01	2.5600140E+00	−1.9687116E+00
3	−7.7068397E−01	2.7743135E−01	2.0383002E+00	7.4259109E−01
4	1.3698992E+01	−3.8132984E+01	5.1107685E+01	−2.7851932E+01
5	1.4799995E+00	1.8815842E+01	−1.1654772E+02	1.7961509E+02
6	2.3119410E+00	−1.5309306E+01	2.6135941E+01	−1.0762516E+01
7	−2.7569022E−01	1.7783105E−01	−4.9261478E−02	3.9419268E−03
8	1.7970251E−04	−2.1611961E−02	4.0098433E−03	1.4790761E−03
9	2.0967820E−02	4.6775947E−03	−9.1757326E−04	−4.2752923E−04
10	4.2054637E−02	−1.3115957E−02	2.7031329E−03	−1.9876871E−04

TABLE 12

EXAMPLE 6 - ASPHERIC SURFACE DATA				
SURFACE NUMBER	KA	A4	A6	A8
1	3.6898607E−02	4.1325089E−02	7.7959667E−02	−3.1320039E−01
2	−2.3337736E+01	−7.0438383E−02	1.2689897E−01	−1.6510709E−02
3	1.4512180E+00	1.0524624E−01	2.7959740E−01	−1.2882128E−01
4	3.1182039E+00	2.0460167E−01	9.3788710E−01	−3.1083520E+00
5	7.0000900E−01	−1.7148265E−01	2.9051562E−01	−5.2650666E−02
6	3.5470814E−01	−1.9176138E−01	1.7502659E−01	−3.4890662E−01
7	−2.3602970E+00	−7.2840681E−02	−8.4242604E−01	2.9509268E+00
8	−1.8311731E+00	−2.6699460E−01	9.1126040E−02	−1.0539776E−01
9	1.0044588E−01	−7.9144306E−01	7.1344844E−01	−2.9852745E−01
10	−1.0909351E+01	−3.3970419E−01	2.9895759E−01	−1.5487925E−01
	A10	A12	A14	A16
1	7.3615786E−01	−1.2805754E+00	1.0422927E+00	−4.0402215E−01
2	−3.3618937E−01	−3.1710410E−01	1.2488311E+00	−7.8867528E−01
3	−6.9518976E−01	8.8551140E−01	3.3513814E−01	−5.9764108E−01
4	1.1989263E+01	−2.7274104E+01	4.1138655E+01	−2.6221811E+01
5	1.2799215E+00	−6.0805643E−01	−6.5701417E+00	1.0955959E+01
6	8.6734211E−01	−1.2626762E+00	8.7271985E−01	−1.2234385E−01
7	−8.6810396E+00	1.3687948E+01	−1.1500705E+01	3.7304276E+00
8	1.2739701E−02	−7.4356044E−02	6.4549028E−02	−1.2957543E−02
9	5.3475537E−02	1.5902396E−03	−1.9540075E−03	1.7122320E−04
10	5.0278107E−02	−9.7894164E−03	1.0056192E−03	−4.1181094E−05

TABLE 13

VALUES IN CONDITIONAL EXPRESSIONS							
EXPRESSION NUMBER	CONDITIONAL EXPRESSIONS	EXAMPLE 1	EXAMPLE 2	EXAMPLE 3	EXAMPLE 4	EXAMPLE 5	EXAMPLE 6
(1)	f/f1	1.8	1.7	1.68	2.49	2.88	2.04
(2)	f/f2	−1.22	−0.98	−1.1	−1.83	−1.88	−1.25
(3)	f/f12	0.91	0.98	0.84	1.17	1.52	1.14
(4)	f/f345	−0.2	−0.37	−0.08	−0.42	−1.04	−0.48
(5)	f1/f3	0.15	0.05	0.2	−0.03	−0.3	−0.16
(6)	(R3f − R3r)/ (R3f + R3r)	−0.18	−0.03	−0.48	0.73	0.98	0.95
(7)	f/f5	−0.55	−1.1	−1.88	−1.51	−2.43	−0.83
(8)	f· tanω/R5r	1.7	0.86	1.5	1.66	1.44	1.64
(9)	f/f3	0.27	0.09	0.34	−0.06	−0.86	−0.33
(10)	D7/f	0.12	0.12	0.14	0.11	0.08	0.08

What is claimed is:

1. An imaging lens substantially consisting of, in order from an object side, five lenses of:

a first lens that has a positive refractive power and has a meniscus shape which is convex toward the object side;

a second lens that has a biconcave shape;

a third lens that has a meniscus shape which is convex toward the object side;

a fourth lens that has a meniscus shape which is convex toward an image side; and

a fifth lens that has a negative refractive power and has at least one inflection point on an image side surface,

wherein the following conditional expression (1) is satisfied:

$$1.4<f/f1<4 \quad (1), \text{ where}$$

f is a focal length of a whole system, and

f1 is a focal length of the first lens, and

wherein the following conditional expression (3) is further satisfied:

$$0.78<f/f12<2.5 \quad (3), \text{ where}$$

f12 is a composite focal length of the first lens and the second lens.

2. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$-3<f/f2<-0.85 \quad (2), \text{ where}$$

f2 is a focal length of the second lens.

3. The imaging lens, as defined in claim **1**, wherein the fourth lens has a positive refractive power.

4. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$-2<f/f345<0 \quad (4), \text{ where}$$

f345 is a composite focal length of the third to fifth lenses.

5. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$-0.5<f1/f3<0.4 \quad (5), \text{ where}$$

f3 is a focal length of the third lens.

6. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$-1<(R3f-R3r)/(R3f+R3r)<1.2 \quad (6), \text{ where}$$

R3f is a paraxial radius of curvature of an object side surface of the third lens, and

R3r is a paraxial radius of curvature of an image side surface of the third lens.

7. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$-4<f/f5<-0.2 \quad (7), \text{ where}$$

f5 is a focal length of the fifth lens.

8. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$0.5<f\cdot\tan\omega/R5r<10 \quad (8), \text{ where}$$

ω is a half angle of view, and

R5r is a paraxial radius of curvature of the image side surface of the fifth lens.

9. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$-0.9<f/f3<0.7 \quad (9), \text{ where}$$

f3 is a focal length of the third lens.

10. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$0.05<D7/f<0.2 \quad (10), \text{ where}$$

D7 is a spacing on an optical axis between the third lens and the fourth lens.

11. The imaging lens, as defined in claim **1**, further comprising an aperture stop that is disposed on the object side of an object side surface of the second lens.

12. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$1.5<f/f1<3.5 \quad (1\text{-}1).$$

13. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$-2.5<f/f2<-0.9 \quad (2\text{-}1), \text{ where}$$

f2 is a focal length of the second lens.

14. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$0.8<f/f12<2 \quad (3\text{-}1), \text{ where}$$

f12 is a composite focal length of the first lens and the second lens.

15. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$-1.5<f/f345<-0.05 \quad (4\text{-}1), \text{ where}$$

f345 is a composite focal length of the third to fifth lenses.

16. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$-0.4<f1/f3<0.2 \quad (5\text{-}1), \text{ where}$$

f3 is a focal length of the third lens.

17. The imaging lens, as defined in claim **1**, wherein the following conditional expression is further satisfied:

$$-0.6<(R3f-R3r)/(R3f+R3r)<1 \quad (6\text{-}1), \text{ where}$$

R3f is a paraxial radius of curvature of the object side surface of the third lens, and

R3r is a paraxial radius of curvature of the image side surface of the third lens.

18. The imaging lens, as defined in claim **1**, wherein when a composite refractive power of the first to third lenses is positive, the following conditional expression is further satisfied:

$$-3<f/f5<-0.4 \quad (7\text{-}1), \text{ where}$$

f5 is a focal length of the fifth lens.

19. An imaging apparatus comprising:

the imaging lens, as defined in claim **1**.

20. An imaging lens substantially consisting of, in order from an object side, five lenses of:

a first lens that has a positive refractive power and has a meniscus shape which is convex toward the object side;

a second lens that has a biconcave shape;

a third lens that has a meniscus shape which is convex toward the object side;

a fourth lens that has a meniscus shape which is convex toward an image side; and

a fifth lens that has a negative refractive power and has at least one inflection point on an image side surface,

wherein the following conditional expression (1) is satisfied:

$$1.4<f/f1<4 \quad (1), \text{ where}$$

f is a focal length of a whole system, and

f1 is a focal length of the first lens, and

wherein the following conditional expression (4) is further satisfied:

$$-2<f/f345<0 \quad (4), \text{ where}$$

f345 is a composite focal length of the third to fifth lenses.

21. An imaging lens substantially consisting of, in order from an object side, five lenses of:

a first lens that has a positive refractive power and has a meniscus shape which is convex toward the object side;

a second lens that has a biconcave shape;

a third lens that has a meniscus shape which is convex toward the object side;

a fourth lens that has a meniscus shape which is convex toward an image side; and

a fifth lens that has a negative refractive power and has at least one inflection point on an image side surface,

wherein the following conditional expression (1) is satisfied:

$$1.4<f/f1<4 \quad (1), \text{ where}$$

f is a focal length of a whole system, and

f1 is a focal length of the first lens, and

wherein the following conditional expression (5-1) is further satisfied:

$$-0.4<f1/f3<0.2 \quad (5\text{-}1), \text{ where}$$

f3 is a focal length of the third lens.

* * * * *

OPTICAL AND ELECTRO-OPTICAL ENGINEERING SERIES

MODERN LENS DESIGN
A Resource Manual

WARREN J. SMITH
GENESEE OPTICS SOFTWARE, INC.

ROBERT E. FISCHER & WARREN J. SMITH, Series Editors

Chapter

3

Improving a Design

3.1 Standard Improvement Techniques

There are several classic design modification techniques which can be reliably used to improve an existing lens design. They are:

1. Split an element into two (or more) elements
2. Compound a singlet into a doublet (or triplet)
3. Raise the index of the positive singlets
4. Lower the index of the negative singlets
5. Raise the index of the elements in general
6. Aspherize a surface (or surfaces)
7. Split a cemented doublet
8. Use unusual partial dispersion glasses to reduce secondary spectrum (see Chap. 6, "Telescope Objectives")

The simple, straightforward application of these techniques is no guarantee of improvement in a lens, in that they do not automatically correct the defects that they are intended to address. In general, these changes tend to reduce the aberration contributions of the modified components; in order to take full advantage of this, the aberrations of the balance of the system must be reduced as well. The operative principle is this: if large amounts of aberrations are corrected or balanced by equally large amounts of aberrations of opposite sign, then the residual aberrations also tend to be large. Conversely, if the balancing aberrations are both small, then the residuals tend to be correspondingly small.

3.2 Glass Changes: Index and *V* Value

The refractive characteristics of the materials used in a lens are obviously significant and important to the design. In general, for a posi-

tive element, the higher the index the better. The higher index reduces the inward Petzval curvature which plagues most lenses. It also tends to reduce most of the other aberrations as well. As an example, see Fig. 3.1, which clearly indicates the effect of higher index in reducing the spherical aberration of a single element. This sort of reduction is primarily a result of the fact that the surface curvature required to produce a given element power is inversely proportional to

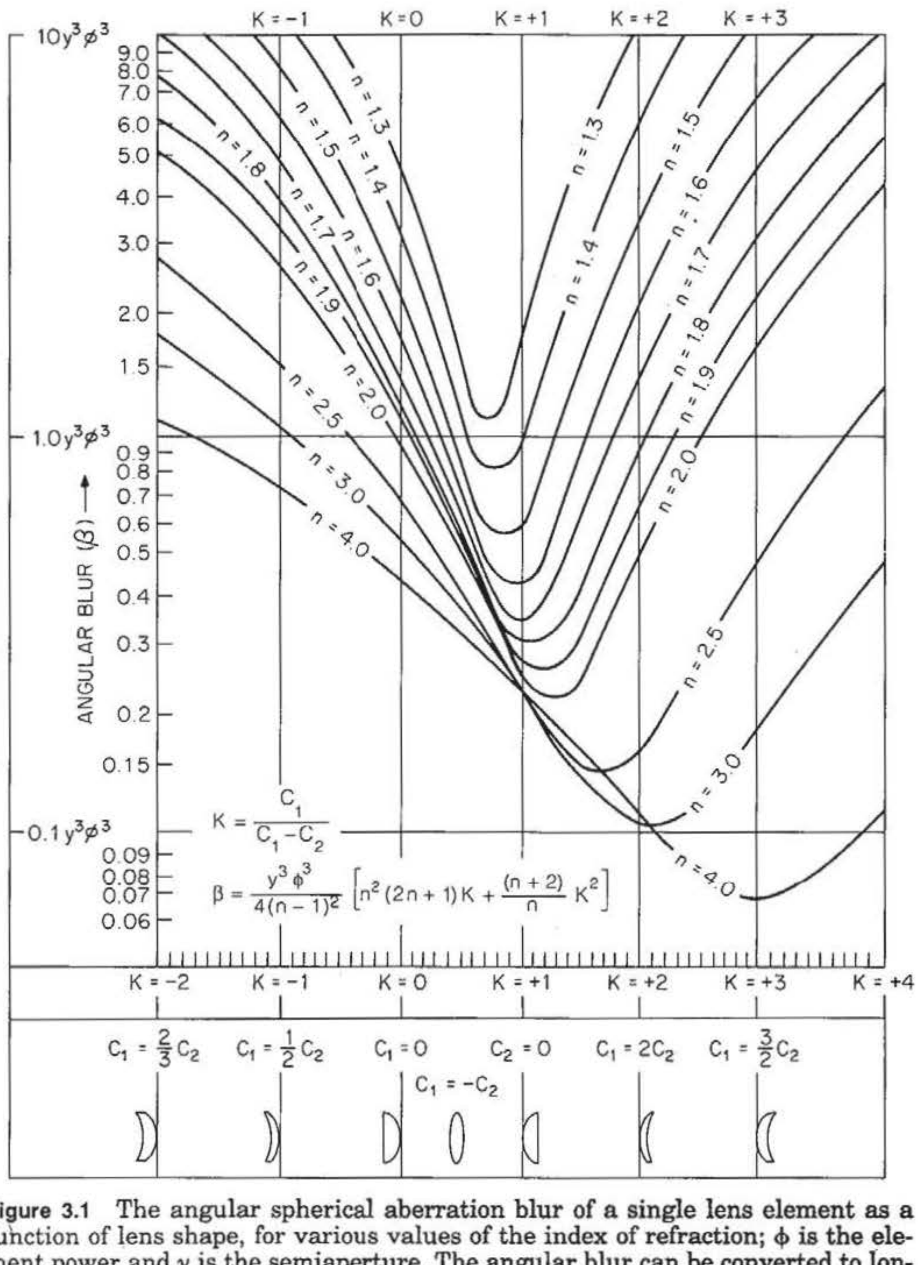


Figure 3.1 The angular spherical aberration blur of a single lens element as a function of lens shape, for various values of the index of refraction; ϕ is the element power and y is the semiaperture. The angular blur can be converted to longitudinal spherical aberration by LA = $2B/y\phi^2$, or to transverse aberration by TA = $-2B/\phi$. (The object is at infinity.)

$(n - 1)$. The improvement also results from the reduction of the angles of incidence at the surfaces of the element.

In a negative element, the situation is less clear. From the standpoint of the Petzval correction, a low index would increase the overcorrecting contribution of a negative element. This can help to offset the (inward) undercorrection which is a major problem in most lenses. On the other hand, a higher index would reduce the surface curvatures and have a generally desirable effect on the overall state of correction. The situation is usually resolved with the negative elements made from a glass along the glass line boundary of the glass map (Fig. 2.2).

A high V value for the positive element and a low V value for the negative element of an achromatic doublet reduce the element powers; this is ordinarily desirable. In lenses (such as the Cooke triplet) where the relative V values of separated elements control the element spacing or the system length, this desideratum may be overridden by other concerns.

Note that, as usual, when you are dealing with components of negative focal length, many of the considerations outlined above are reversed. In a negative achromatic doublet, the negative element is often made of crown glass and the positive is made of flint. Here a high-index (flint) positive element will reduce the inward Petzval curvature, as will a low-index (crown) negative element.

3.3 Splitting Elements

Splitting an element into two (or more) approximately equal parts whose total power is equal to the power of the original element can reduce the aberration contribution by a significant factor. The reason that this reduces aberrations is that it allows the angles of incidence to be reduced; the nonlinearity of Snell's law means that smaller angles introduce less aberration than do large ones. This technique is often used in high-speed lenses to reduce the zonal spherical residual and in wide-angle lenses to control astigmatism, distortion, and coma.

Figure 3.2 shows the thin lens third-order spherical aberration for spherical-surfaced positive elements which are shaped (or bent) to minimize the undercorrected spherical. The upper plot shows the spherical as a function of the index of refraction for a single element with a distant object. The curve labeled $i = 2$ shows the spherical for two elements whose total power is equal to that of the single element. The best split is 50-50—i.e., the split elements have equal power; this minimizes the spherical. (The same is true for a split into more than two elements, i.e., three, four, etc., as shown in the curves labeled $i = 3$ and $i = 4$.) The improvement produced by splitting an element in

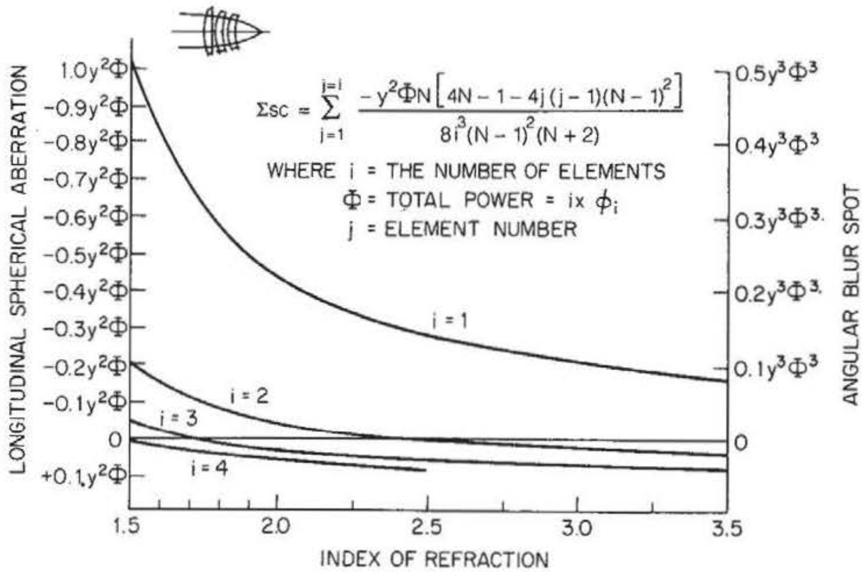


Figure 3.2 The spherical aberration of one, two, three, and four thin positive elements, each bent for minimum spherical aberration, plotted as a function of the index of refraction, and showing the reduction in the amount of aberration produced by splitting a single element into two or more elements (of the same total power). Each plot is labeled with *i*, the number of elements in the set. (The object is at infinity.)

two can be seen to be a factor of about 5 for lenses of index equal to 1.5. The higher the index, the greater the reduction; for an index of 1.8, the factor is about 7. At an index of 2.5 or higher, the spherical can be brought to zero or even overcorrected with just two positive elements. Most other aberrations are similarly affected by splitting, although it should be obvious that neither Petzval nor chromatic is changed by splitting.

In high-speed lenses this technique is frequently used to reduce the residual zonal spherical; the positive elements are split. This illustrates the basic idea. If the residual zonal spherical is negative (undercorrected), one splits a positive element; in the rare event that the zonal is positive (overcorrected), one would split a negative element. A similar philosophy can be applied for troublesome residuals of the other aberrations as well.

The choice of which element to split is often less apparent. The logical candidate would obviously seem to be the element which contributes most heavily to the problem aberration. (An examination of the third- and fifth-order surface contributions can often locate the source of the aberration.) However, other considerations often become significant. For example, in the Cooke triplet, the rear element is the prime candidate for the split, and such a split is quite effective in reducing

the zonal spherical, as Figs. 14.1 and 14.2 will attest. But the better choice for the split is the front element, not because it does a better job of reducing the zonal spherical, but because the resulting lens is better corrected for the other aberrations. Figure 14.3 shows the simple split-front triplet. This is the ancestor of the Ernostar family of lenses; Figs. 14.10 through 14.15 illustrate designs which can be considered as descendants from the split-front triplet. Although they have been largely superseded by the more powerful double-Gauss form, they are nonetheless excellent design types.

Many retrofocus and wide-angle lenses which use strong outer meniscus negative elements illustrate the use of this technique for the control of coma, astigmatism, and distortion by splitting these negative elements.

The implementation of this technique with an automatic design program is often far from easy. For example, if one decides to split one of the crowns of a Cooke triplet and simply replaces one crown with two, after the computer optimization has run its course, the resultant lens may look like an ordinary triplet with a narrow cracklike airspace in the split element (a *cracked crown triplet*). The performance of the lens is the same as the original triplet; the split has not improved a thing. This is because the original lens was in a local optimum of the merit function. Aberrations other than the zonal spherical dominated the design; this caused the program to return the lens to its original design configuration. What is necessary in this situation is to force the split elements into a configuration which will accomplish the desired result.

Consider the split-front triplet. There are two ways to get to a design like Fig. 14.3. One approach is to make the lens so fast that the zonal spherical is by far the single dominant aberration in the merit function. Then the program will probably choose a form which reduces the zonal spherical; the lens shapes in Fig. 14.3 are a likely result. A difficulty with this approach may be that you aren't interested in a very fast lens, or if you are, the rays may miss the surfaces of the initial design completely, or encounter TIR. The alternative approach is to constrain the front elements to a configuration in which the spherical is minimized. Simply fixing the first element to a plano-convex form (by not allowing the plano surface curvature to vary) or holding the second to an aplanatic meniscus shape is usually sufficient to obtain a stable design which is enough different from the cracked crown triplet. When this has been accomplished the constraint can be released and the automatic design routine allowed to find what is (one hopes) a new and better local optimum. The problem here is that this approach presupposes a knowledge of the configuration which will

produce a good result. Obviously a knowledge of both aberration theory and of successful design forms is a useful tool to the designer.

3.4 Separating a Cemented Doublet

Airspacing a cemented doublet can provide two additional degrees of freedom: two bendings instead of one, plus an airspace. While this technique does not have the inherent aberration reduction capability that many other modifications possess, the extra variables may indirectly make a design improvement possible. A difficulty in implementing this is that the refraction at the cemented surface is apt to become much more abrupt when it is split into two glass-air interfaces than when it was a cemented surface; in fact rays may encounter TIR if a simple split is attempted without a concomitant reduction of the angle of incidence. Manual intervention in the form of adjusting the radii to reduce the angle of incidence is often necessary.

3.5 Compounding an Element

Compounding a singlet to a doublet can be viewed in two different ways:

1. As a way of simulating a desirable but nonexistent glass type
2. As a way of introducing a cemented interface into the element in order to control the ray paths

Note that in almost all examples of Tessar-type lenses (and other types which utilize compounded elements), the doublets have positive elements with high index and high V values, while the negative element of the doublet has both a lower index and V value. See Chap. 12 for examples.

The longitudinal axial chromatic of a singlet is given by $LA_{ch} = -f/V$. Thus a fully achromatized lens (with $LA_{ch} = 0.0$) has the chromatic characteristic of a lens made from a material with a V value of infinity; a partially achromatized doublet acts like a singlet with a very high V value.

The Petzval radius of a singlet is given by $\rho = -nf$, where n is its index. An *old achromat* with a low-index crown and a higher-index flint has a shorter Petzval radius than a singlet of the crown glass. For example, an achromat of BK7 (517:649) and SF1 (717:295) has a Petzval radius $\rho = -1.37f$; in other words, in regard to Petzval field curvature, it behaves like a singlet with an index of 1.37. A *new achromat* has a high-index crown and a lower-index flint. A new

achromat of SSKN5 (658:509) and LF5 (581:409) has a Petzval radius $\rho = -2.19f$ and a Petzval curvature which is characteristic of a singlet with an index of 2.19.

Thus an achromatized (or partially achromatized) doublet with a high-index positive element and a low-index negative element has many of the characteristics of a lens made of a high-index, high-V-value crown glass. (Note that for a negative focal length doublet, the reverse is true.) Both conditions are usually to be desired, in order to flatten the Petzval field and to achieve achromatism.

Figure 3.3 shows a singlet, an old achromat, and a new achromat, each with the same focal length. The equivalent V value of each achromat is, of course, equal to infinity. The Petzval radius for each is given in the figure caption.

The cemented interface of the doublet can be used for specific control of specific rays. In a lens such as the Tessar, where the doublet is located well away from the aperture stop, the upper and lower rim rays of the oblique fan have very different angles of incidence at the cemented surface. In Fig. 3.4 it can be seen that the angle of incidence at this surface is much larger for the upper ray than for the lower. In this type of lens the cemented surface is typically a convergent one, and the (trigonometric) nonlinear characteristic of Snell's law means that the upper ray is, in this case, refracted downward more than it would be were the refraction linear with angle. Thus the upper ray is deviated in such a way as to reduce any positive coma of this ray. This

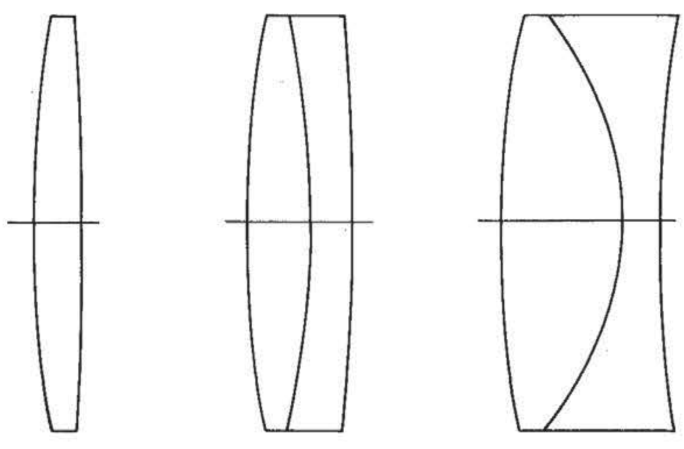


Figure 3.3 Three lenses, each with the same focal length f. (*a*) A singlet of BK7 (517:642) glass; Petzval radius equals $-1.52f$. (*b*) An old achromat of BK7 (517:642) and SF1 (717:295) glasses; Petzval radius equals $-1.37f$. (*c*) A new achromat of SSKN5 (658:509) and LF5 (581:409); Petzval radius is $-2.19f$.

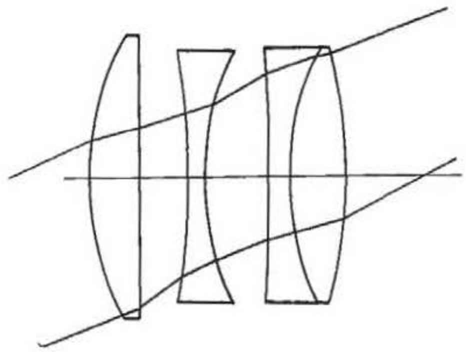


Figure 3.4 The upper and lower rim rays have significantly different angles of incidence at the cemented interface in the rear doublet of this Tessar design. Properly handled, this difference can be used to modify the correction of the coma-type aberrations.

illustrates the manner in which a cemented surface can be used for an asymmetrical effect on an oblique beam.

The Merté surface

A strongly curved, collective cemented surface with a small index break (to the order of 0.06) has an effect which can be used to reduce the undercorrected zonal spherical aberration. The central doublet of the Hektor lens shown in Fig. 3.5 illustrates this principle. The ce-

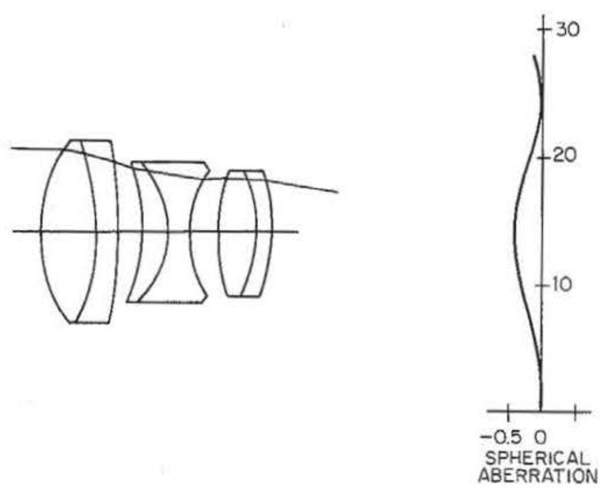


Figure 3.5 The cemented surface in the center doublet of this Hektor lens is what is called a Merté surface. The index break $(n' - n)$ across the surface is small, but at the margin of the aperture the angle of incidence for the axial ray becomes quite large. This combination produces an undercorrecting seventh-order spherical aberration which, as the plot shows, dominates the spherical aberration at the margin of the aperture, causing the marginal spherical to be negative rather than the usual positive value.

mented surface is a collective one (in that $[n' - n]/r$ is positive) and contributes undercorrected spherical aberration. For rays near the axis, the spherical aberration contribution of the surface is modest. However, when the ray intersection height increases and the angle of incidence becomes large, as shown in Fig. 3.5, the trigonometric nonlinearity of Snell's law causes the amount of ray deviation to be disproportionately increased. This causes the undercorrection from this surface to dominate the spherical aberration. The result is a spherical aberration characteristic like that shown in Fig. 3.5. The spherical in the central part of the aperture appears quite typical: the undercorrected third-order dominates close to the axis and the overcorrecting fifth-order causes the plot to curve back as the ray height increases. However, toward the edge of the aperture the undercorrection of the Merté surface becomes dominant and the aberration plot reverses direction again. The net result is the equivalent of a reduced zonal spherical aberration.

It is rare to see as extreme an example of the Merté surface as that illustrated in the Hektor of Fig. 3.5. Such a surface is very sensitive to fabrication errors and is thus expensive to make. It is also often best used close to the aperture stop because, if it is located away from the stop, the asymmetrical effects described two paragraphs above can become quite undesirable. However, it is well worth noting that an ordinary collective cemented surface has a tendency to behave as a mild Merté surface and to reduce the spherical zonal, at least somewhat.

3.6 Vignetting and Its Uses

Vignetting, which is simply the mechanical limitation or obstruction of an oblique beam, is usually regarded primarily as something which reduces the off-axis illumination in the image. However, vignetting often plays an essential role in determining the off-axis image quality as well as the illumination. Of course there are many applications for which vignetting cannot be tolerated; the illumination must be as uniform as possible across the entire field of view. The complexity of the lens design, therefore, must be sufficient to produce the required image quality at full aperture over the full field.

But for many applications, vignetting is, in fact, quite tolerable. In commercial applications the clear apertures may well be established so as to be just sufficient to pass the full aperture rays for the axial image. It is not at all unusual for vignetting to exceed 50 percent at the edge of the field. For a camera lens, this vignetting will, of course, completely disappear when the iris of the lens is stopped down to an aperture below the vignetting level. Since camera lenses are most of-

ten used at less than full aperture, the vignetting is not as significant as it is in a lens which is always used at full aperture, such as a microscope or projection lens.

The *benefit* of vignetting is that it cuts off the upper and/or lower rim rays of the oblique tangential fan. Since these are ordinarily the most poorly behaved rays, the image quality may well be improved by their elimination. Most lenses which cover a significant field are afflicted with oblique spherical aberration, a fifth-order aberration which looks like third-order spherical aberration, but which varies as the square of the field angle. And since its magnitude is different for sagittal than for tangential rays, it can be seen to have characteristics of both astigmatism and spherical aberration. Oblique spherical aberration usually causes the rays at the edge of the oblique bundle to show strongly overcorrected spherical aberration; vignetting is a simple way to block these aberrant rays from the image.

Another factor favoring the use of vignetting is that it results from lens elements with small diameters. In general, one can count on a smaller-diameter lens being less costly to fabricate.

For a camera lens, one must be certain that the iris diaphragm is located centrally in the oblique beam so that, when the iris is closed down, the central rays of the beam are the ones which are passed. These are usually the best-corrected rays of the oblique beam. Also this location assures that the vignetting will be eliminated at the largest possible aperture.

3.7 Eliminating a Weak Element; the Concentric Problem

Occasionally an automatic design program will produce a design with an element of very low power. Frequently this means that the element can be removed from the design without adversely affecting the quality of the design. Often a straightforward removal will not work; the design process may simply "blow up." An approach which usually works (if anything will) is to add the thickness and the surface curvatures of the element to the merit function with target values of zero, allowing them to continue as variable parameters. Sometimes targeting the difference between the two curvatures is also useful. Usually, if the element isn't necessary to the design, a few cycles of optimization, possibly with gradually increasing weights on these targets, will change the element to a very thin, nearly plane parallel plate, which can then be removed without severe trauma to the design. If your design program will not accept curvatures and thicknesses as targets, an alternative technique is to remove the curvatures and the thickness as variables and to gradually weaken the curvatures and reduce

the thickness (by hand) while continuing to optimize with the other variables.

An unfortunate form of the "weak" element is a fairly strongly bent meniscus, which the computer uses for a relatively important design function, such as the correction of spherical aberration or the reduction of the Petzval curvature. It is rarely possible to eliminate such an element because it is an integral part of the design. The unfortunate aspect of this situation is that, if the surfaces of the meniscus element are concentric or nearly so, the customary centering process used in optical manufacture is impossible or impractical, and the element is costly to fabricate. This situation can be ameliorated by forcing the centers of curvature of the surfaces apart by a distance sufficient to allow the use of ordinary centering techniques. Again, including the required center-to-center spacing in the merit function and reoptimizing will usually modify the offending element to a more manufacturable form without any significant damage to the system performance.

3.8 Balancing Aberrations

The optimum balance of the aberrations is not always the same in every case; the best balance varies with the application and depends on the size of the residual aberrations. In general, for well-corrected lenses, the aberrations should be balanced so as to minimize the OPD, i.e., the wavefront variance, but there are significant exceptions.

Spherical aberration

If a lens is well-corrected and the high-order residual spherical aberration is small, so that the OPD is to the order of a half-wave or less, then the best correction is almost always that with the marginal spherical corrected to zero, as illustrated in Fig. 3.6*b*. However, when the zonal spherical is large, there are two situations where one may want to depart from complete correction of the marginal spherical.

If the lens will always be used at full aperture (as a projection lens, for example), and if the spherical aberration residual is large (say to the order of a wave or so), the diffraction effects will be small when compared to the aberration blur; then the spherical aberration should be corrected to minimize the size of the blur spot rather than to minimize the OPD. This will produce the best contrast for an image with relatively coarse details, i.e., for a resolution well below the diffraction limit. As an example, at a speed of *f*/1.6, a 16-mm projection lens has a diffraction cutoff frequency of about 1100 line pairs per millimeter (lpm). But its performance is considered quite good if it resolves 100

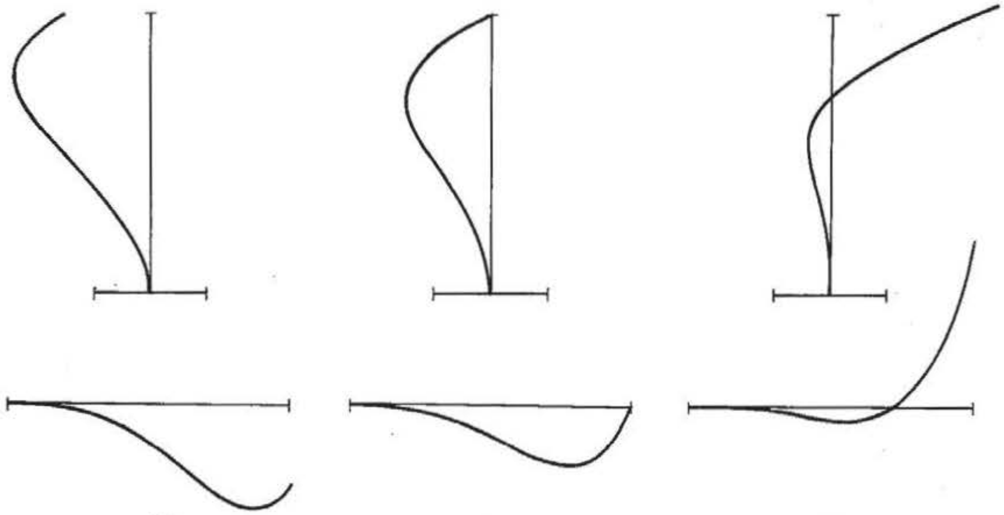


Figure 3.6 Three states of correction of spherical aberration are shown. Each has the same amount of fifth-order spherical, but different amounts of third-order. (*a*) Spherical aberration balanced to give the smallest possible size blur spot. This correction may be optimum when the aberration is large and the required level of resolution is low compared to the diffraction limit. (*b*) Spherical aberration balanced for minimum OPD. This is optimum when the system is diffraction-limited. (*c*) Spherical aberration balanced to minimize the focus shift as the lens aperture is stopped down. This correction is used in camera lenses when the residual spherical is large. The upper row is longitudinal spherical versus ray height; the lower row is transverse ray intercept plots.

lpm, an order of magnitude less than the diffraction limit. Such a lens can advantageously be corrected for the minimum diameter geometrical blur spot. This state of correction occurs (for third- and fifth-order spherical) when $LA_z = 1.5LA_m$, or $TA_z = 1.05TA_m$; the result is a high-contrast, but low-resolution, image. This correction is illustrated in Fig. 3.6*a*. See also the comments on defocusing in Secs. 2.4 and 2.7.

For a lens which is used at varying apertures, as is a typical camera lens, it is important that the best focus position not shift as the size of the aperture stop is changed. If the spherical aberration is corrected at the margin of the aperture, or corrected as described in the paragraph above, the position of the best focus will shift as the aperture is changed. The best focus will move toward the paraxial focus as the aperture is reduced. The state of correction which is often used in such a case is overcorrection of the marginal spherical, as shown on Fig. 3.6*c* (assuming an undercorrected zonal residual). The result is a design in which the focus is quite stable as the lens is stopped down. The *resolution* is better than it would be otherwise, but, at full aperture, the *contrast* in the image is quite low. This works out reasonably well in a high-speed camera lens because camera lenses are only infrequently used at full aperture. Typically, photographs are taken with the lens

stopped down well below the full aperture, and, when the camera is stopped down, this state of correction yields a much better photograph.

The three correction states shown in Fig. 3.6 also indicate the manner in which the spherical aberration is changed when the third-order aberration is changed. This is a typical situation often encountered in lens design: the fifth- (and higher-) order aberrations are relatively stable and difficult to change, but the third order is easily modified (by bending an element, for example). In the figure, all three illustrations have exactly the same amount of fifth-order spherical; the difference is solely in the amount of third-order. Note that, in the (upper) longitudinal plots, the change from one illustration to the next varies as y^2, whereas in the (lower) transverse plots the differences vary as y^3.

Chromatic aberration and spherochromatism

Here the question is how to balance the spherochromatism, which typically causes the spherical aberration at short (blue) wavelengths to be overcorrected and that at the long (red) wavelengths to be undercorrected. If the aberration is small (diffraction-limited), the best correction is probably with the chromatic aberration corrected at the 0.7 zone of the aperture. This means that the central half of the aperture area is undercorrected for color and the outer half of the aperture is overcorrected, as shown in Fig. 3.7*a*. But if the amount of the aberration is large, the spherical overcorrection of the blue marginal ray causes a blue flare and a low contrast in the image. In these circumstances the correction zone can advantageously be moved to (or toward) the marginal zone, as shown in Fig. 3.7*b*. This will probably reduce the resolution somewhat, because it increases the size of the core of the image blur, but it improves the contrast significantly and yields a more pleasing image, free of the blue flare and haze. This state of correction is accomplished by increasing the undercorrection of the chromatic aberration of the paraxial rays.

Astigmatism and Petzval field curvature

In a typical anastigmat lens the fifth-order astigmatism tends to become significantly undercorrected (i.e., negative) as the field angle is increased. In order to minimize the astigmatism over the full field, the third-order astigmatism is made enough overcorrected to balance the undercorrected fifth-order astigmatism. The result is the typical field curvature correction with the sagittal focal surface located inside the tangential focal surface in the central part of the field because of the overcorrected third-order astigmatism, and the reverse arrangement

Chapter

10

Telephoto Lenses

10.1 The Basic Telephoto

The arrangement shown in Fig. 10.1, with a positive component followed by a negative component, can produce a compact system with an effective focal length F which is longer than the overall length L of the lens. The ratio of L/F is called the *telephoto ratio,* and a lens for which this ratio is less than unity is classified as a telephoto lens. The smaller the ratio, the more difficult the lens is to design. Note that many camera lenses which are sold as telephoto lenses are simply long-focal-length lenses and are not true telephotos.

Many of the comments in Chap. 9 regarding retrofocus or reverse telephoto lenses are equally applicable to the telephoto lens. Equations 9.1 and 9.2 may also be applied to the telephoto. The usual Petzval problem is with a backward-curving field, just as with the retrofocus, and the same glass choices are appropriate for the telephoto. Since the system is unsymmetrical, each component must be individually achromatized if both axial and lateral color are to be cor-

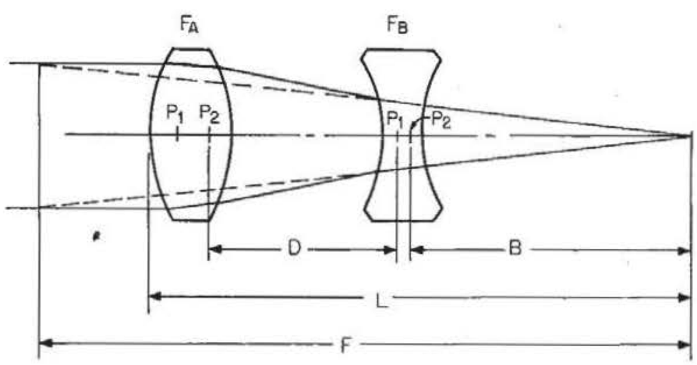


Figure 10.1 The basic power arrangement for a telephoto lens yields a compact lens with an overall length which is less than its effective focal length.

rected. The aperture stop is usually at the front member or part way toward the rear. Since a telephoto lens usually covers only a relatively small angular field, coma, distortion, and lateral color (which in many lenses are reduced by an approximate symmetry about the stop) are not as troublesome as they would be with a wider field.

10.2 Close-up or Macro lenses

The correction of a long-focal-length unsymmetrical lens is usually quite sensitive to a change in object distance, and, for most telephoto lenses, the image quality deteriorates severely when they are focused on nearby objects. Note that this effect varies inversely with the object distance expressed in focal length units; i.e., for a given design type, the image quality may remain acceptable as long as the object distance exceeds some number of focal lengths. Thus, for a given object distance, this effect is more of a problem for a long-focal-length lens than for a short. Since retrofocus lenses tend to have short focal lengths, this problem is somewhat less frequently encountered, in spite of their asymmetry.

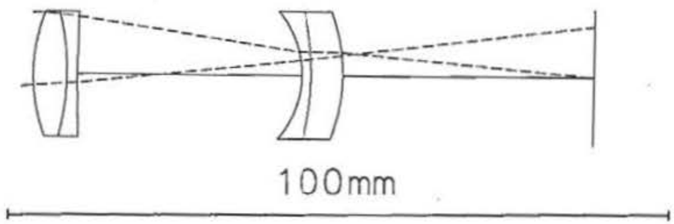
Many newer telephoto lenses and the specialized close-focusing lenses (called *macro* lenses) utilize a floating component or separately moving elements to maintain the aberration correction when the lens is focused at a close distance. For many lenses, the spherical aberration and the astigmatism become undercorrected at close conjugates. Thus a relative motion of the elements to increase the marginal ray height on a negative (or overcorrecting) element/component can be used to stabilize the spherical. The astigmatism can be controlled by a motion which increases the height of the chief ray on a component which contributes overcorrected astigmatism, or which reduces it on an undercorrecting one.

The design of such a system is carried out just like the design of a zoom lens. Two (or more) configurations are set up, one with a long (perhaps infinite) object conjugate distance and the other with a short one. The computer then uses the same lens elements with different spacings for each configuration and optimizes the merit function for both configurations simultaneously.

Figures 19.3 to 19.6, and 20.5 show nontelephoto designs with macro features.

10.3 Sample Telephoto Designs

Figures 10.2 and 10.3 show two very basic telephoto lenses; each consists of just two cemented or closely airspaced achromatic doublets, about as simple a construction as possible. Figure 10.2 covers less



KINGSLAKE TELEPHOTO MODIFIED BY HOPKINS

radius	thickness	mat'l	index	V-no	sa
24.607	5.080	BK7	1.517	64.2	9.2
-36.347	1.600	F2	1.620	36.4	9.2
212.138	12.300	air			9.0
	21.699	air			6.7
-14.123	1.520	BK7	1.517	64.2	9.4
-38.904	4.800	F2	1.620	36.4	9.4
-25.814	37.934	air			9.4

EFL = 101.6
BFL = 37.93
NA = -0.0893 (F/5.6)
GIH = 7.44
PTZ/F = -19.38
VL = 47.00
OD infinite conjugate

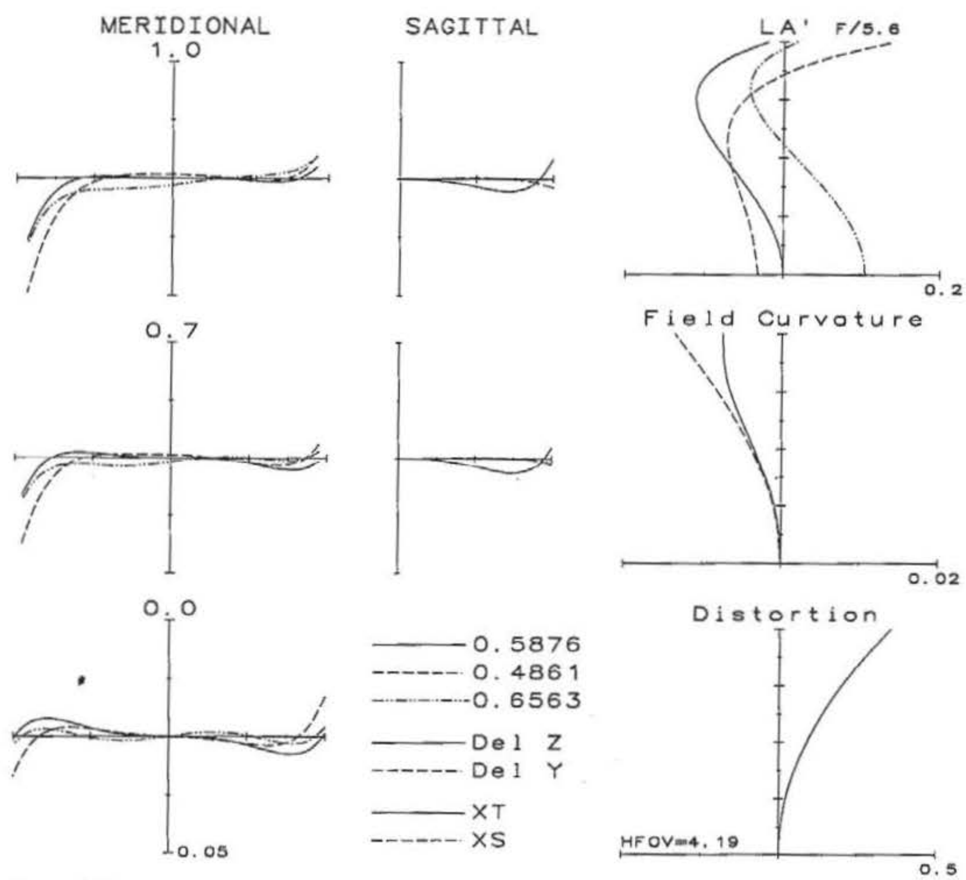
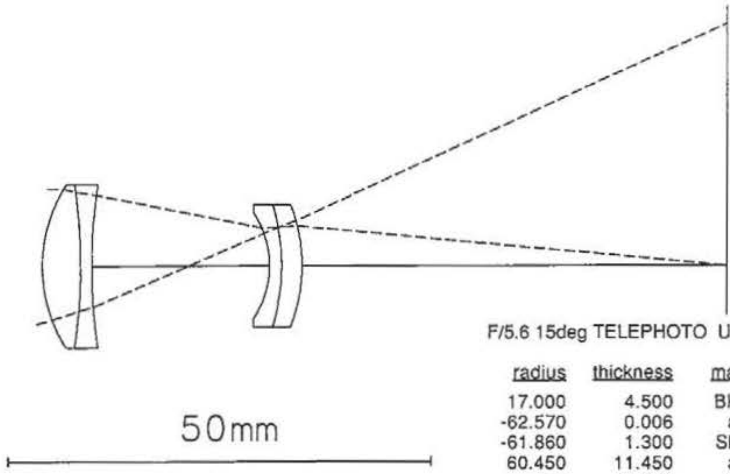


Figure 10.2



F/5.6 15deg TELEPHOTO US 2,390,387

radius	thickness	mat'l	index	V-no	sa
17.000	4.500	BK7	1.517	64.2	9.3
-62.570	0.006	air			9.3
-61.860	1.300	SF2	1.648	33.8	9.3
60.450	11.450	air			9.3
	9.540	air			6.1
-10.610	1.400	KF9	1.523	51.5	6.0
-24.760	0.011	air			7.0
-24.250	2.400	SF1	1.717	29.5	7.0
-18.570	50.137	air			7.0

EFL = 98.52
BFL = 50.14
NA = -0.0888 (F/5.6)
GIH = 26.60 (HFOV=15.11)
PTZ/F = 16.55
VL = 30.61
OD infinite conjugate

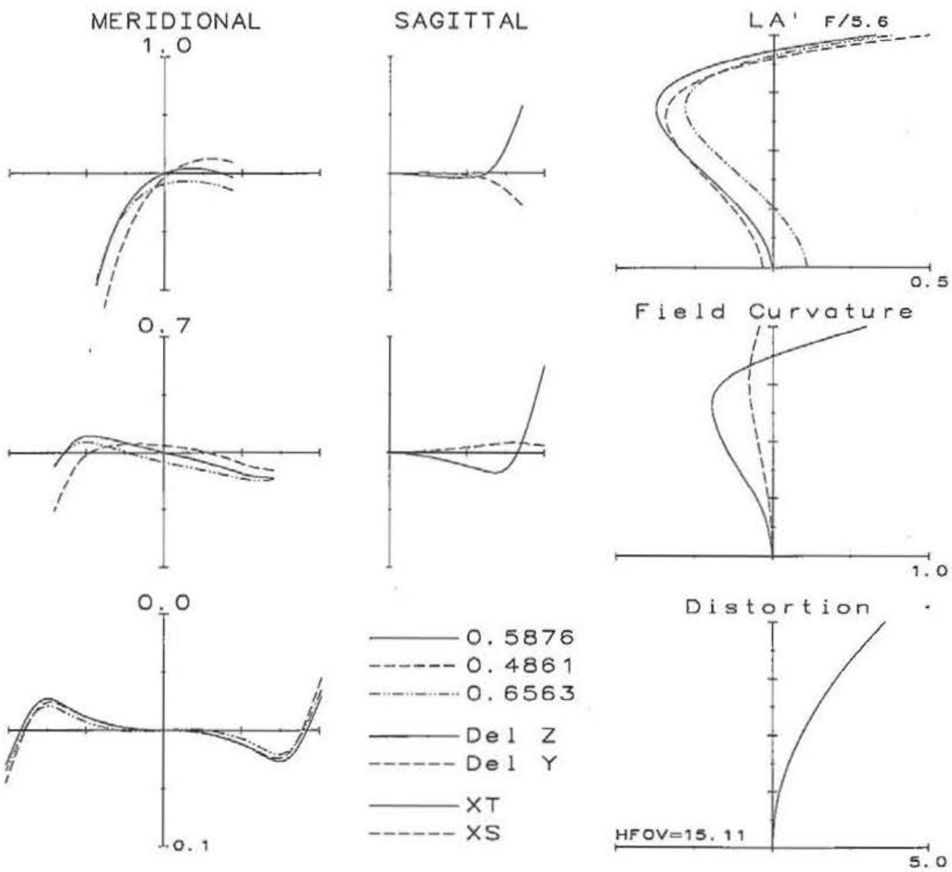


Figure 10.3

than 9° at *f*/5.6 and has a telephoto ratio of 0.85; it uses BK7 and F2 glasses and was done as an illustrative design exercise. Figure 10.3, at the same speed, covers 3 times as large a field with a telephoto ratio of 0.81. It utilizes heavier flint glasses (higher index and lower V value) to achieve a modestly improved performance.

Figure 10.4 covers a 30° field at *f*/4.5 with excellent distortion correction, illustrating the benefits derived from the added degrees of freedom gained by splitting the cemented doublets into widely airspaced components. The large telephoto ratio of 0.91 and the modestly high-index glasses are also helpful.

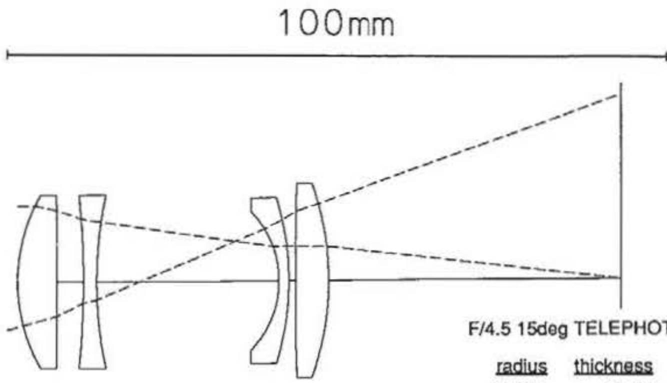
Figure 10.5 illustrates the use of unusual partial dispersion glasses (as described in Chap. 6) to reduce the secondary spectrum. The term *superachromat* implies that at least four wavelengths are brought to a common focus, whereas the term *apochromat* indicates that three wavelengths are corrected. Notice, however, that the spherochromatism and zonal spherical aberration in this lens are much larger than the axial chromatic aberration; these are the aberrations which will determine the limiting performance of this lens.

Figures 10.6, 10.7, and 10.8 each have five elements and illustrate some of the different ways that the inherent capabilities of this configuration can be utilized. In Figs. 10.6 and 10.8, the crown element of the front doublet is split into two elements to reduce the zonal spherical aberration (among others). Figure 10.6 is the result of a classroom exercise which specified a 200-mm *f*/5.0 lens with a telephoto ratio of 0.80 for a 35-mm camera. It uses quite ordinary glasses and achieves an excellent level of performance. Figure 10.7 uses high-index glass and a different arrangement to get to a speed of *f*/4.0, but falls a bit short in performance and telephoto ratio (at 0.91). Figure 10.8 uses unusual partial dispersion glasses and breaks the contact in the front doublet, to achieve what is (potentially) a high level of correction, although the telephoto ratio is only a modest 0.95.

Figure 10.9 uses seven elements to produce a well-corrected *f*/5.6, 6° field lens with an extremely short telephoto ratio of 0.66. Notice the overcorrected Petzval field, with $\rho/f = +2.1$; this is one reason that small telephoto ratios are troublesome.

With a telephoto ratio of 1.06, Fig. 10.10 doesn't really qualify as a true telephoto, but at a speed of *f*/1.8 and a field of 18°, it is an interesting lens, even if it is difficult to classify.

Figures 10.11 and 10.12 show an internal-focusing telephoto with a modest ratio of 0.92. The front component is fixed and the lens is focused for close-ups by moving the rear component toward the image plane. This could be considered as a sort of macro-style lens.



F/4.5 15deg TELEPHOTO JOSA 1950 KAZAMAKI & KONDO

radius	thickness	mat'l	index	V-no	sa
24.840	6.000	SSKN5	1.658	50.9	12.7
-671.820	4.000	air			12.7
-123.600	2.000	SF6	1.805	25.4	12.7
58.170	6.530	air			12.7
	21.000	air			7.9
-14.290	1.500	FK3	1.465	65.8	10.2
-39.560	1.000	air			12.2
500.000	5.000	BAF10	1.670	47.1	14.3
-41.470	44.437	air			14.3

EFL = 100
BFL = 44.44
NA = -0.1111 (F/4.5)
GIH = 27.00 (HFOV=15.11)
PTZ/F = -6.285
VL = 47.03
OD infinite conjugate

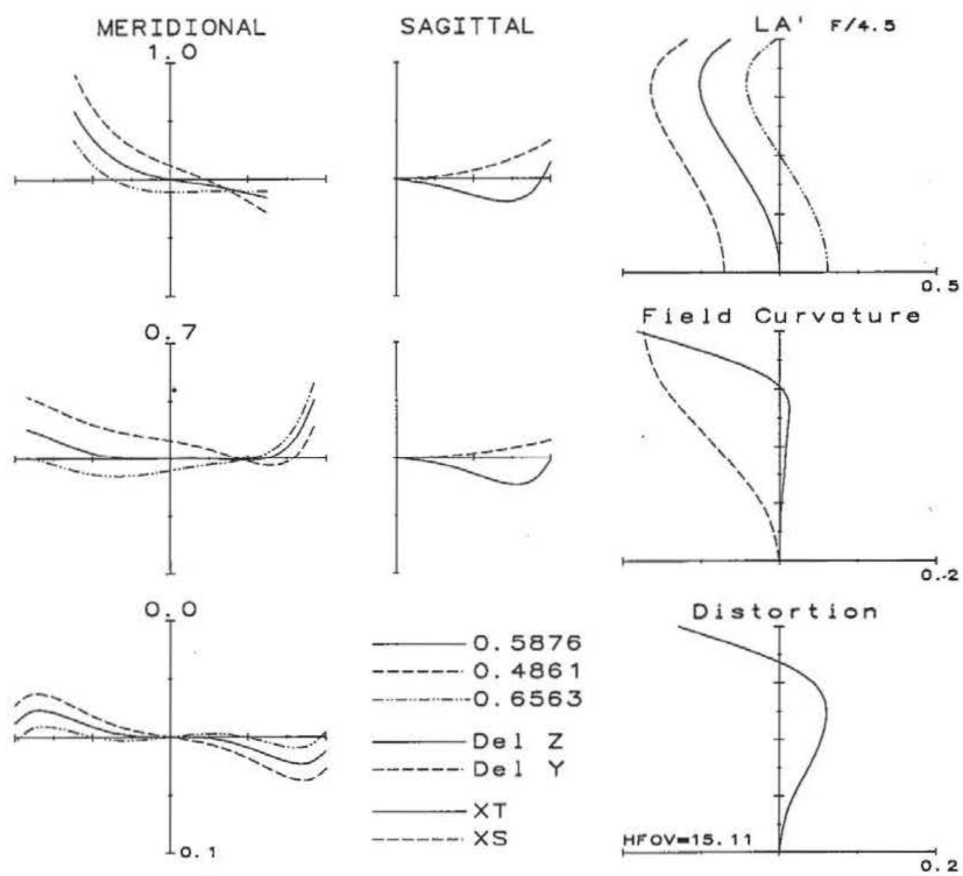
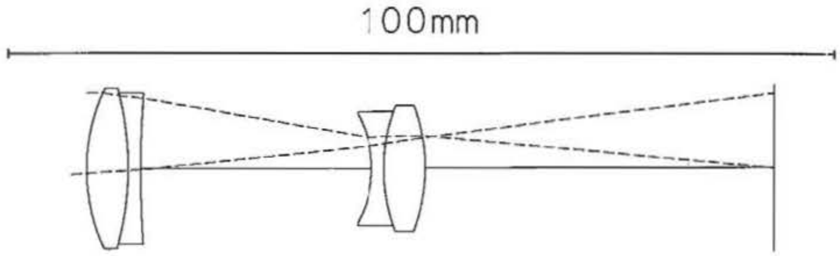


Figure 10.4



SIGLER; SUPER ACHROMAT; TELEPHOTO EFL=254

radius	thickness	mat'l	index	V-no	sa
21.851	5.008	PK51	1.529	77.0	9.5
-34.546	1.502	KZFS9	1.599	46.9	8.9
108.705	1.127	air			8.3
	26.965	air			8.1
-12.852	1.502	KZFS1	1.613	44.3	6.3
19.813	5.008	BASF5	1.603	42.5	6.7
-20.378	42.174	air			7.4

EFL = 100
BFL = 42.17
NA = -0.0898 (F/5.6)
GIH = 8.75
PTZ/F = -40.38
VL = 41.11
OD infinite conjugate

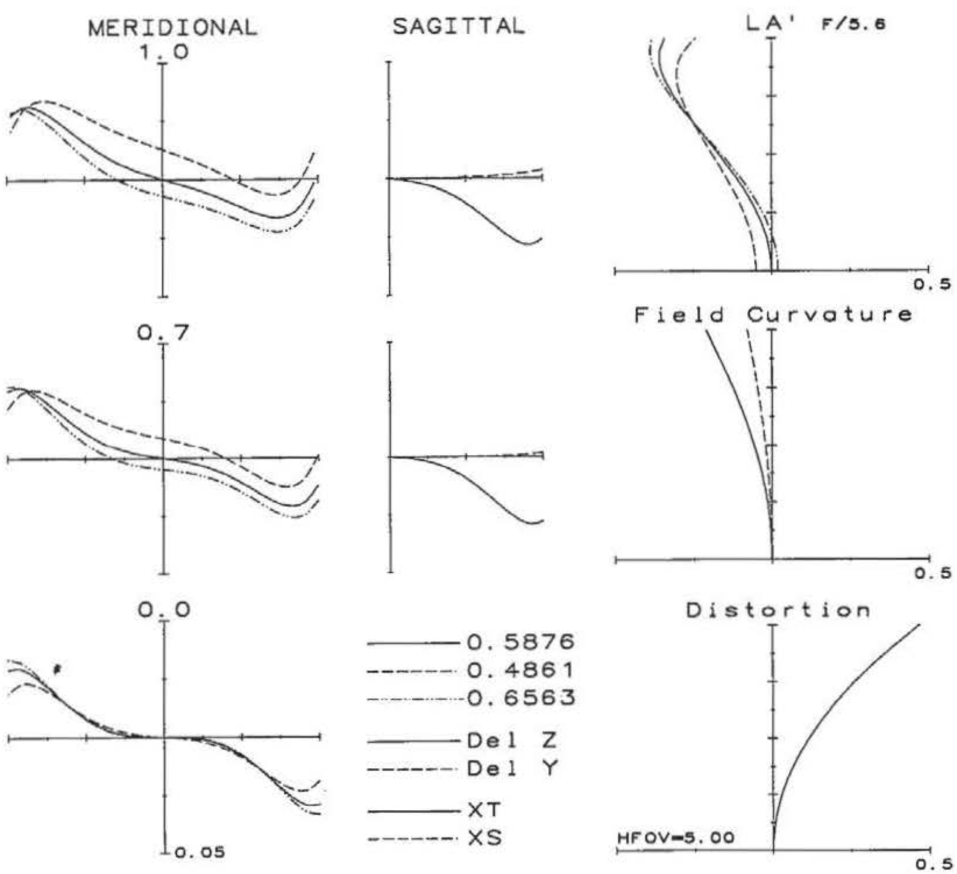
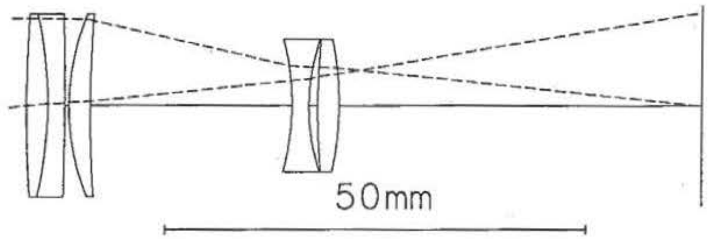


Figure 10.5



F/5 6deg TELEPHOTO

radius	thickness	mat'l	index	V-no	sa
149.035	2.500	SK4	1.613	58.6	10.5
-46.003	2.000	SF14	1.762	26.5	10.5
-477.921	0.500	air			10.5
26.522	2.500	SK4	1.613	58.6	10.5
132.322	24.060	air			10.5
-28.605	2.000	SK4	1.613	58.6	7.6
22.989	1.050	air			7.6
82.834	2.500	F5	1.603	38.0	7.6
-36.911	42.897	air			7.6

EFL = 100
BFL = 42.9
NA = -0.1000 (F/5.0)
GIH = 10.50 (HFOV=5.99)
PTZ/F = 7.68
VL = 37.11
OD infinite conjugate

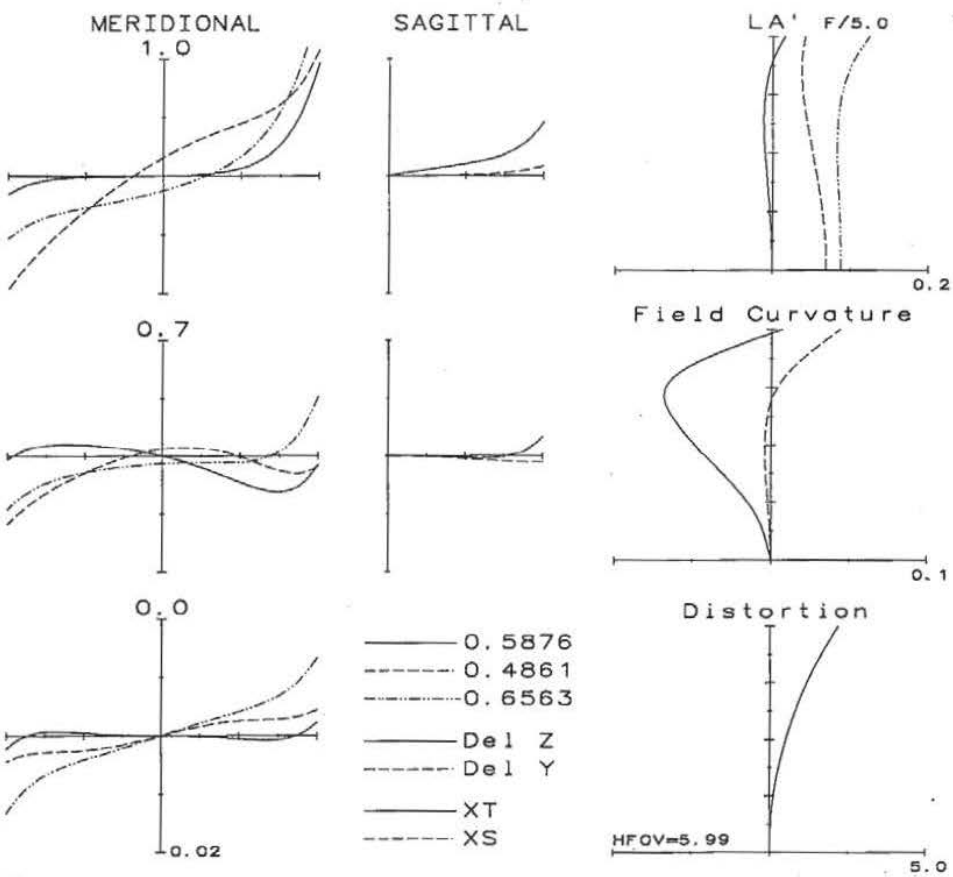
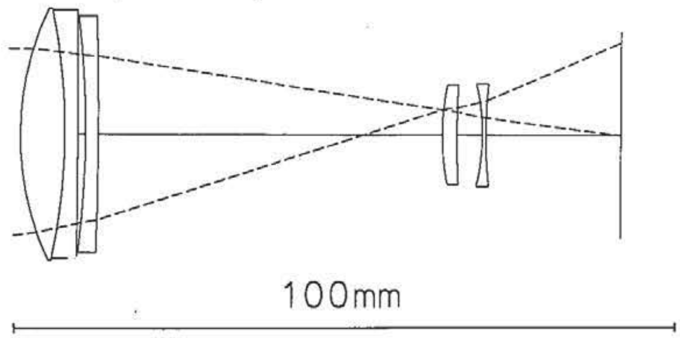


Figure 10.6



J. EGGERT ET AL; USP 3388956; F/4 15 DEG. TELEPHOTO #1

radius	thickness	mat'l	index	V-no	sa
42.156	6.676	LAKN6	1.642	58.0	18.4
-88.214	1.945	SF10	1.728	28.4	18.2
-1800.073	1.183	air			17.4
-137.288	1.945	SF9	1.654	33.7	17.3
-530.649	40.290	air			16.8
	11.913	air			5.4
34.202	2.234	LAF11	1.757	31.7	7.3
117.496	3.859	air			7.3
-31.069	0.526	BSF10	1.650	39.1	7.3
69.782	20.320	air			7.5

EFL = 99.99
BFL = 20.32
NA = -0.1256 (F/4.0)
GIH = 13.16 (HFOV=7.50)
PTZ/F = 4.272
VL = 70.57
OD infinite conjugate

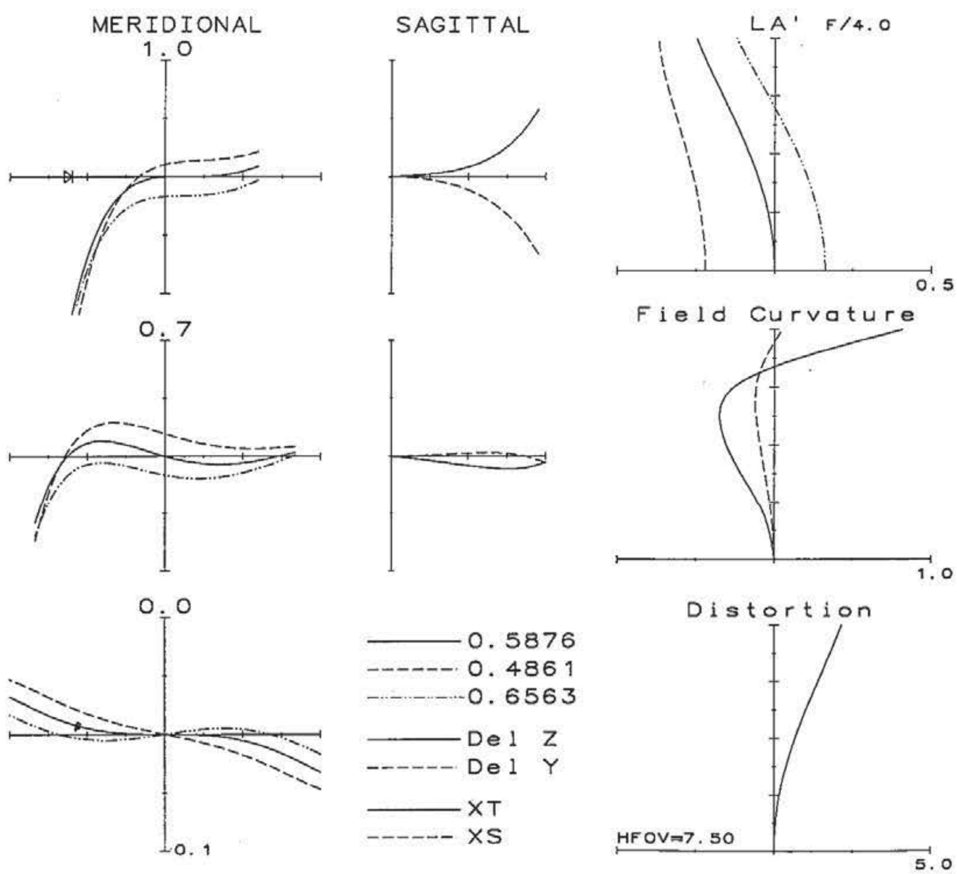
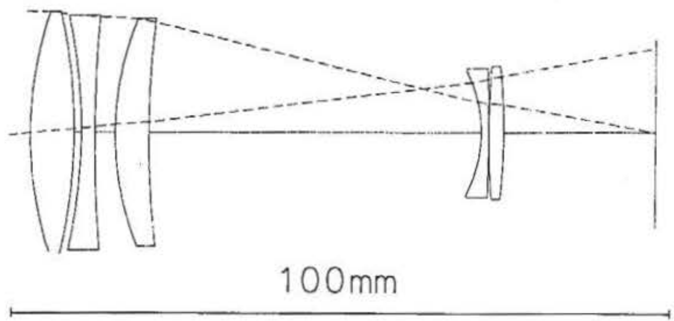


Figure 10.7



SEI MATSUI; USP 4338001; F/2.8 14 DEG. TELEPHOTO LENS #1

radius	thickness	mat'l	index	V-no	sa
54.585	6.667	FCD1	1.497	81.6	17.9
-77.813	1.111	air			17.7
-76.698	2.056	LAFN7	1.750	34.9	17.3
207.222	3.056	air			17.0
43.208	5.111	BED5	1.658	50.9	16.8
134.444	50.667	air			16.2
-19.462	1.111	K3	1.518	59.0	9.0
-305.556	0.056	air			9.5
121.887	2.222	TAF2	1.794	45.4	9.7
-89.277	22.862	air			9.8

EFL = 100
BFL = 22.86
NA = -0.1790 (F/2.8)
GIH = 12.28 (HFOV=7.00)
PTZ/F = -9.12
VL = 72.06
OD infinite conjugate

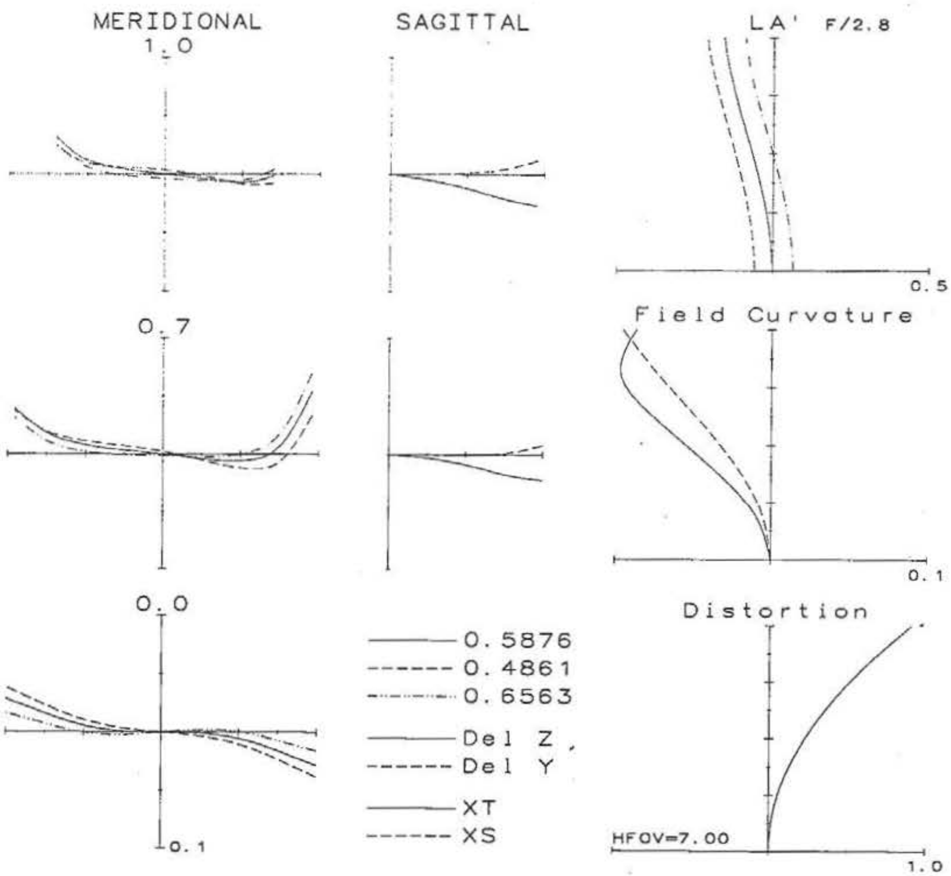
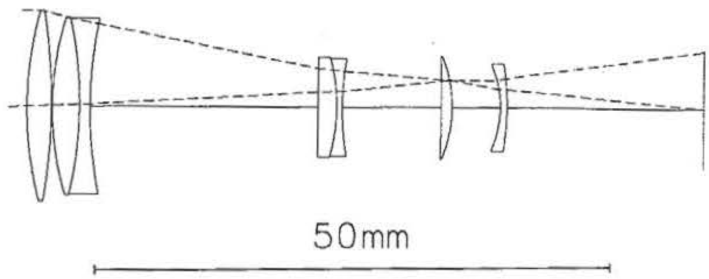


Figure 10.8



MELVYN H. KRÈITZER; USP 4359272; 390 MM F/5.6 6 DEG. TEL. #1

radius	thickness	mat'l	index	V-no	sa
33.072	2.386	C3	1.518	59.0	8.9
-53.387	0.077	air			8.9
27.825	2.657	C3	1.518	59.0	8.4
-35.934	1.025	LAF7	1.749	35.0	8.3
40.900	22.084	air			7.8
	1.794	FD110	1.785	25.7	4.7
-16.775	0.641	TAFD5	1.835	43.0	4.6
27.153	9.607	air			4.5
-120.757	1.035	CF6	1.517	52.2	4.8
-12.105	4.705	air			4.8
-9.386	0.641	TAF1	1.773	49.6	4.0
-24.331	18.960	air			4.1

EFL = 100
BFL = 18.96
NA = -0.0892 (F/5.6)
GIH = 5.24
PTZ/F = 2.097
VL = 46.65
OD infinite conjugate

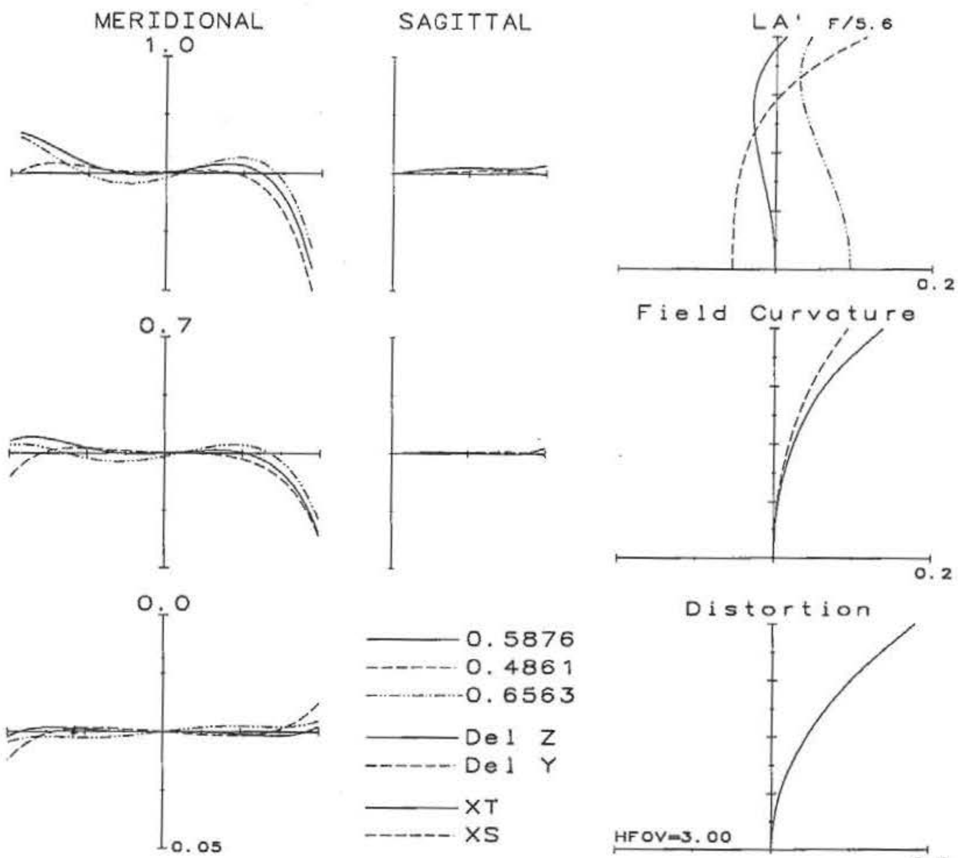
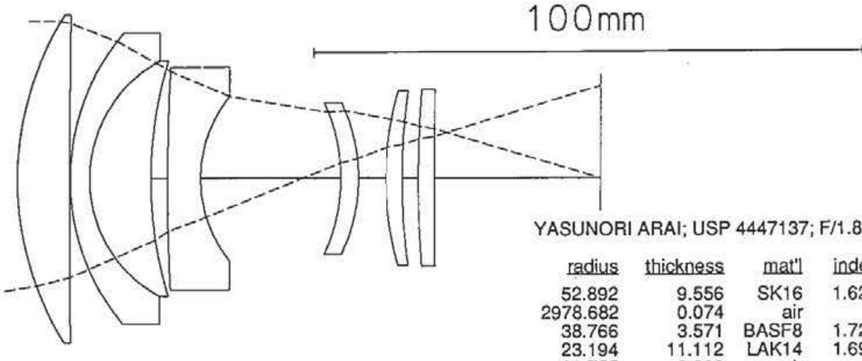


Figure 10.9



YASUNORI ARAI; USP 4447137; F/1.8 TELEPHOTO #2

radius	thickness	mat'l	index	V-no	sa
52.892	9.556	SK16	1.620	60.3	28.9
2978.682	0.074	air			28.9
38.766	3.571	BASF8	1.723	37.9	25.6
23.194	11.112	LAK14	1.697	55.5	20.7
69.755	3.000	air			19.7
341.551	6.052	SF5	1.673	32.1	19.6
22.422	18.520	air			14.5
	6.949	air			12.4
-30.641	3.237	BSF07	1.702	41.2	12.5
-29.652	5.089	air			13.3
53.327	3.000	LAF11	1.720	46.0	15.4
106.470	2.963	air			15.4
184.198	2.963	LAF01	1.700	48.1	15.6
1116.126	30.191	air			15.6

EFL = 100
BFL = 30.19
NA = -0.2779 (F/1.80)
GIH = 16.20 (HFOV=9.20)
PTZ/F = -8.83
VL = 76.09
OD infinite conjugate

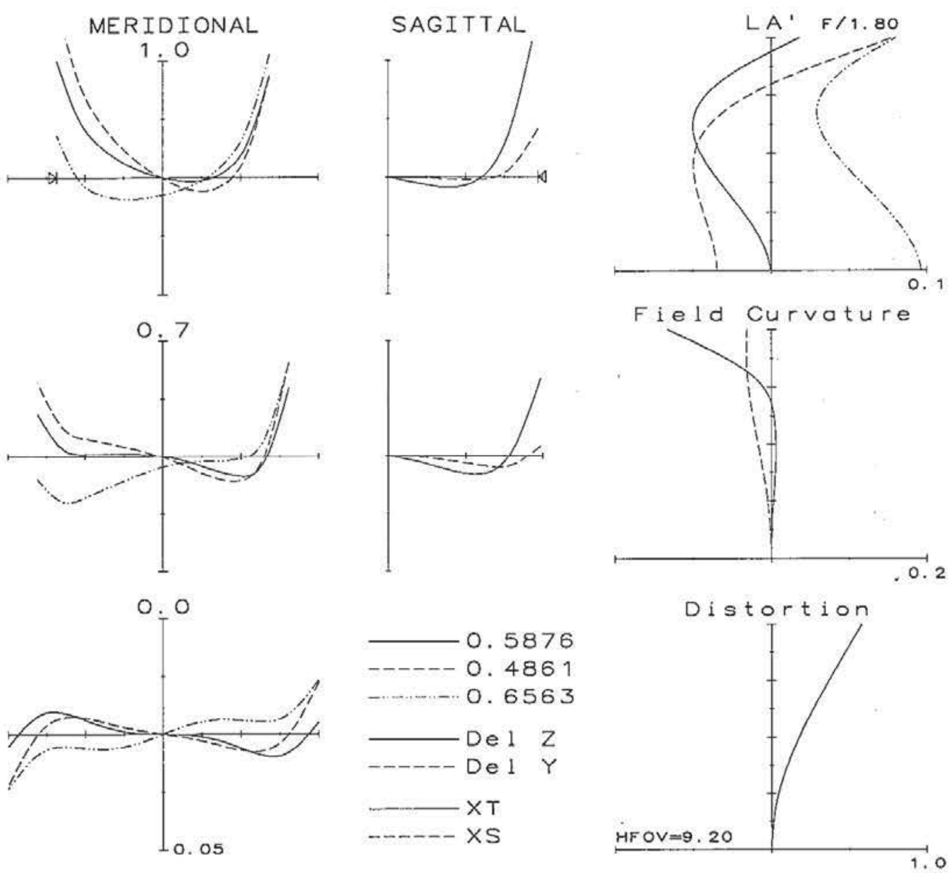
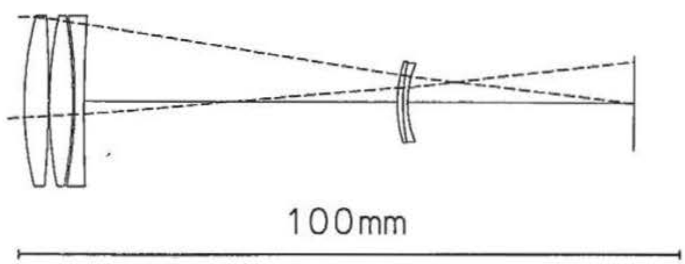


Figure 10.10



MOMIYAMA USP 4,037,935; F/4.5 (LONG EFL POSITION)

radius	thickness	mat'l	index	V-no	sa
48.796	3.645	CAF	1.434	94.9	12.6
-168.096	0.140	air			12.6
62.820	3.505	FK5	1.487	70.2	12.6
-70.733	0.303	air			12.6
-73.188	1.402	LASF3	1.806	40.9	12.6
250.187	22.431	air			12.6
	25.150	air			7.9
19.535	0.841	SF4	1.755	27.5	6.0
27.456	0.701	LSF16	1.772	49.6	5.8
14.524	34.173	air			5.7

EFL = 112.2
BFL = 34.17
NA = -0.1099 (F/4.5)
GIH = 6.06
PTZ/F = -4.07
VL = 58.12
OD infinite conjugate

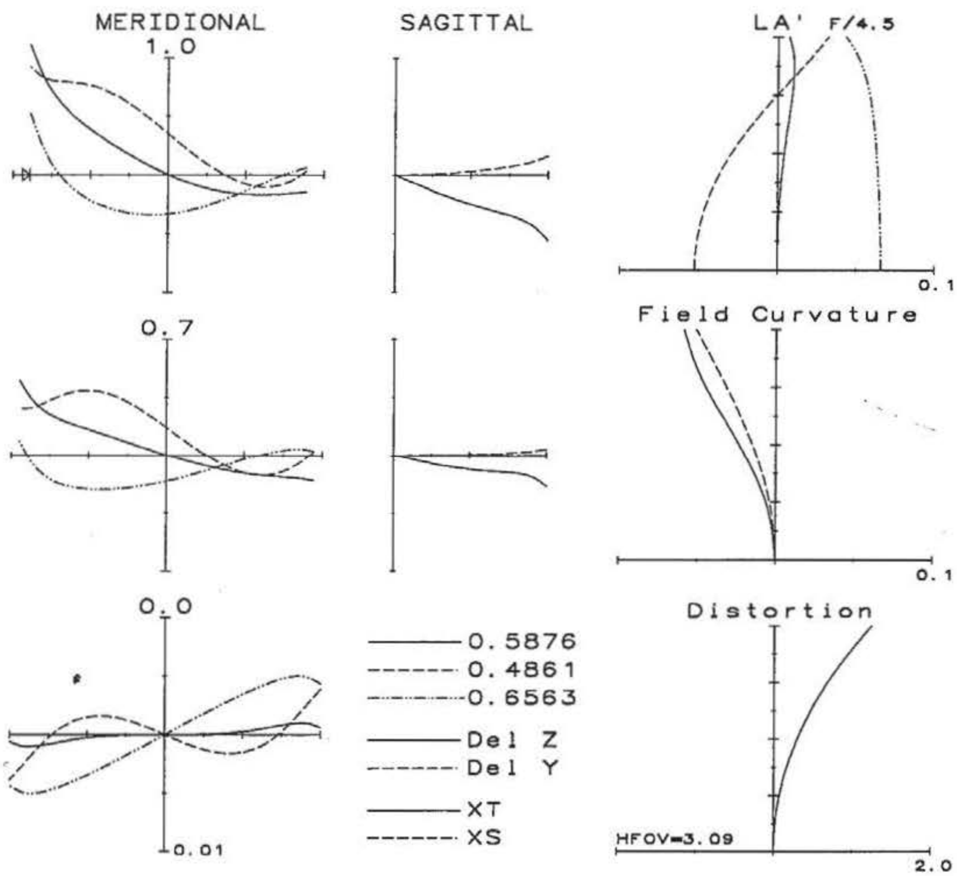
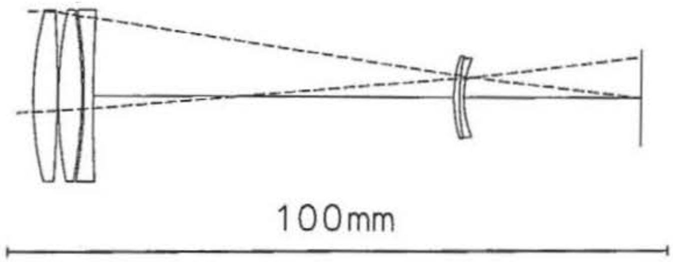


Figure 10.11



MOMIYAMA USP 4,037,935; F/4.5 (SHORT EFL POSITION)

radius	thickness	mat'l	index	V-no	sa
48.796	3.645	CAF	1.434	94.9	12.6
-168.096	0.140	air			12.6
62.820	3.505	FK5	1.487	70.2	12.6
-70.733	0.303	air			12.6
-73.188	1.402	LASF3	1.806	40.9	12.6
250.187	22.431	air			12.6
	32.440	air			7.9
19.535	0.841	SF4	1.755	27.5	6.0
27.456	0.701	LSF16	1.772	49.6	5.8
14.524	26.657	air			5.7

EFL = 100
BFL = 26.66
NA = -0.1139 (F/4.4)
GIH = 5.93
PTZ/F = -4.605
VL = 65.41
OD = 2243.07 (MAG = -0.048)

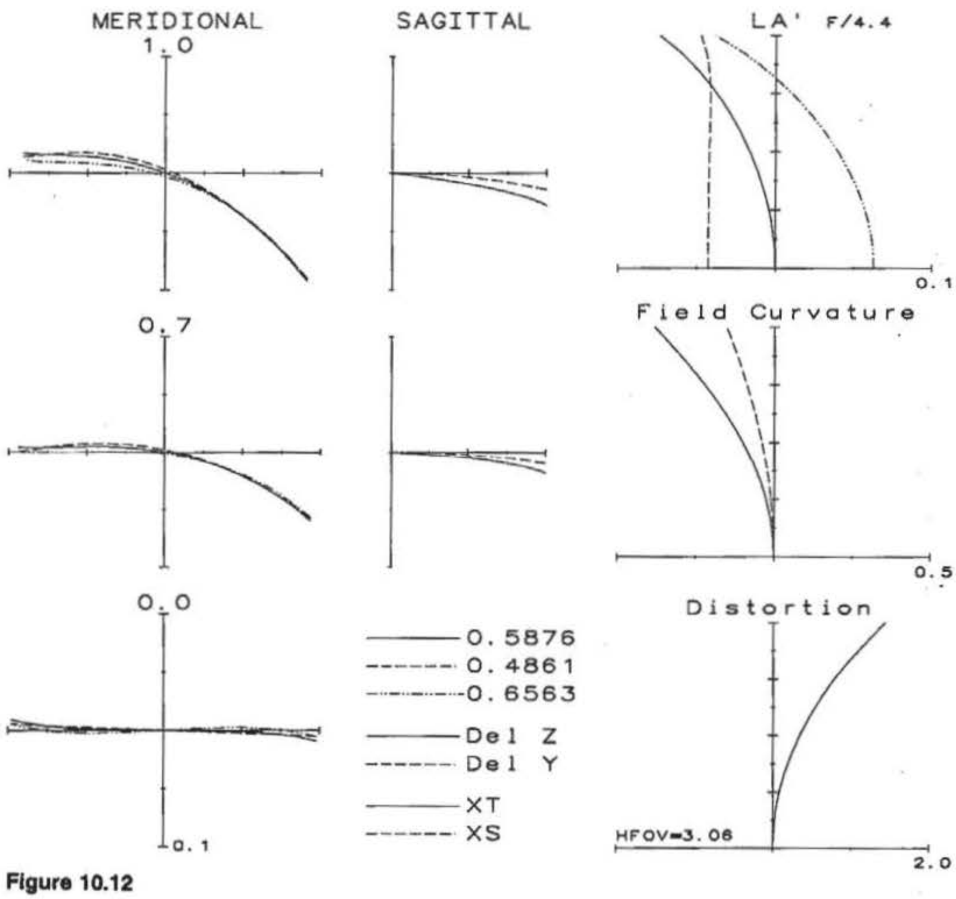


Figure 10.12

Polymer Optics: A manufacturer's perspective on the factors that contribute to successful programs

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Polymer Optics: A manufacturer's perspective on the factors that contribute to successful programs

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ABSTRACT

Precision polymer optics is a key enabling technology allowing the deployment of sophisticated devices with increasingly complex optics on a cost competitive basis. This is possible because of the incredible versatility that polymer optics offers the designer. The unique nature of injection molding demands a very disciplined approach during the component design and development phase. All too often this process is poorly understood. We will discuss best practices when working with a polymer optics manufacturer. This will be done through an examination of the process of creating state-of-the-art polymer optics and a review of the cost tradeoffs between design tolerances, production volumes, and mold cavitation.

Keywords: Optical fabrication, injection molding optics, polymer optics, plastic optics, optical systems design

1. INTRODUCTION

Polymer optics is a key optical technology enabling a wide array of sophisticated devices. Because these types of optics are made of plastic and through the process of injection molding many options exists for providing customized solutions to unique engineering and product problems. However, the tremendous flexibility available to the designer is at once a bonus and a burden. It's a bonus because of the potential for creative problem solving. The burden comes from not understanding how the optics are made, how they're toleranced, and how alternative solutions may accomplish the goal-albeit with a different design.

While many options are available the challenge for designers is to understand the manufacturing process behind these solutions so that they can design their programs to leverage the technology. Without this level of understanding the designer may not achieve an optimal solution. Or, as is sometimes the case, the design team may go away thinking that a polymer optic is not an appropriate solution after all. We call this not knowing what you don't know. From a manufacturer's perspective many times we have encountered programs where we were given a small glimpse of what the engineering team was trying to achieve. This is often presented as a set of disembodied specifications for a particular optic. Frequently this comes in the form of a request to substitute the existing expensive glass substrate for a 'cheaper' plastic one. It's not unusual to hear something like, "the specs are on the drawing, just substitute the word acrylic for the word BK-7."

While this approach sometimes works, more often than not the challenges in making polymer optics a commercial success are completely ignored. The glass-appropriate specifications, which are completely wrong for plastic, result in either a no bid or an optic that works but could have been customized for plastic to work even better.

It is our belief that given the challenges and opportunities, designers are well served by getting the manufacturer involved early on in program discussions, since it is the optimal time to insert manufacturability expertise. To that end we will discuss the polymer optics manufacturing process and examine the best practices to use when working with a polymer optics manufacturer.

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2. WHAT ARE POLYMER OPTICS

Polymer optics are precision optics that are made of thermoplastics. Materials such as acrylic, styrene, Topas, Zeonex, and Ultem are examples of thermoplastics. In most instances they are made by a process called injection molding.

There are some exceptions to this. For example, some large area plastic optics, such as Fresnel lenses, are often made using compression molding. We will confine our discussion to optics made using the injection molding process. The technology was pioneered by companies such as Eastman Kodak, Polaroid, and U.S Precision Lens.

Today, in addition to being manufactured in the United States, polymer optics are made in Europe and in Asia, by companies such as Jenoptik in Germany and Nalux in Japan.

2.1 Where are they used, why would you want to use them

The number of devices and instruments that use these types of optics continues to grow. In short, any application that calls for an optical component, be it for imaging, scanning, detection, or illumination is a candidate for using a polymer optic. Some limitations on use will be discussed below.

A partial listing of devices that are in the market place today employing polymer optics would include: barcode scanners (both linear-1D laser scanners and matrix- 2D bar code imagers), biometric security systems, medical devices, document scanners, printers, light curtains, light guides, cameras and mobile imaging, smoke detector optics, automated sanitary valve systems, and laboratory equipment such as spectrometers and particle counters. All of these and more have benefited from using precision polymer optics. Polymer optics are also found in certain telecommunication products and commonly used to replicate micro structured surfaces such as microlens arrays, Fresnel lenses, refractive-diffractive optics, and some types of gratings. They are increasingly being used in LED illumination applications.

2.2 How are they made: the manufacturing technology

Polymer optics are manufactured by injection molding thermoplastics into optical forms. The key ingredients for production are molding resins, the molds, and injection molding machines.

2.2.1 Thermoplastics

As noted above, the principle molding thermoplastics are acrylic, styrene, polycarbonate, cyclic-olefins polymers (such as Zeonex and Zeonor, manufactured by Zeon Chemicals), Cyclic-olefin co-polymers (Topas, manufactured by Topas Advanced Polymers), and other specialty resins such as Ultem., Radel, and Udel. All of these materials are thermoplastics, which means they are plastics that can be heated and cooled repeatedly. This category of polymer is different from the optical grade thermoset plastics, which, once cured, are not able to become molten again. The manufacturers of these materials publish data related to their mechanical, thermal, and optical properties. Optical designers need to understand how these materials behave so that they can arrive at appropriate solutions.

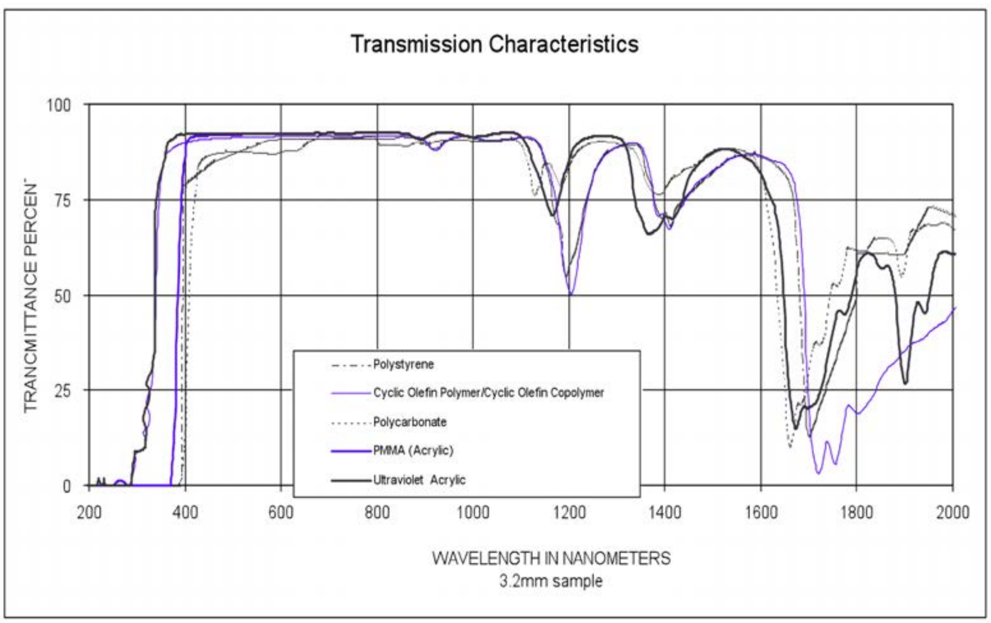
SPECIFICATIONS OF OPTICAL GRADE PLASTICS

Properties	Acrylic (PMMA)	Polycarbonate (PC)	Polystyrene (PS)	Cyclic Olefin Copolymer	Cyclic Olefin Polymer	Ultem 1010 (PEI)
Refractive Index N_F (486.1nm) N_D (589.3nm) N_C (656.3nm)	 1.497 1.491 1.489	 1.599 1.585 1.579	 1.604 1.590 1.584	 1.540 1.530 1.526	 1.537 1.530 1.527	 1.689 1.682 1.653
Abbe Value	57.2	34.0	30.8	58.0	55.8	18.94
Transmission % Visible Spectrum 3.174mm thickness	92	85-91	87-92	92	92	36-82
Deflection Temp 3.6°F/min @ 66psi 3.6°F/min @ 264psi	 214°F/101°C 198°F/92°C	 295°F/146°C 288°F/142°C	 230°F/110°C 180°F/82°C	 266°F/130°C 253°F/123°C	 266°F/130°C 263°F/123°C	 410°F/210°C 394°F/201°C
Max Continuous Service Temperature	198°F 92°C	255°F 124°C	180°F 82°C	266°F 130°C	266°F 130°C	338°F 170°C
Water Absorption % (in water, 73°F for 24 hrs)	0.3	0.15	0.2	<0.01	<0.01	0.25
Specific Gravity	1.19	1.20	1.06	1.03	1.01	1.27
Hardness	M97	M70	M90	M89	M89	M109
Haze (%)	1 to 2	1 to 2	2 to 3	1 to 2	1 to 2	-
Coeff of Linear Exp cm X 10-5/cm/°C	6.74	6.6-7.0	6.0-8.0	6.0-7.0	6.0-7.0	4.7-5.6
dN/dT X 10-5/°C	-8.5	-11.8 to -14.3	-12.0	-10.1	-8.0	-
Impact Strength (ft-lb/in) (Izod notch)	0.3-0.5	12-17	0.35	0.5	0.5	0.60
Key Advantages	Scratch Resistance Chemical Resistance High Abbe Low Dispersion	Impact Strength Temperature Resistance	Clarity Lowest Cost	High moisture barrier High Modulus Good Electrical Properties	Low Birefringence Chemical Resistance Completely Amorphous	Impact Resistance Thermal & Chemical Resistance High Index

Table 1. A brief summary of some of the key characteristics of the most important optical thermoplastics.

2.2.1.1 Light Transmission

Most optical plastics have high clarity in the broad band visible portion of the spectrum. For example, acrylic and some grades of Zeonex have transmission properties of about 92%. Materials such as polycarbonate have lower transmission, but higher impact resistance. The table below summarizes the transmission characteristics of the most commonly used optical polymers.



Graph 1. Transmission characteristics of optical polymers.

2.2.1.2 Index of Refraction and abbe value

The range of available indices of refraction is quite narrow when compared to that available for glass. Acrylics and COP materials behave more like crown glass types (having abbe values in the mid 50s) with an index of refraction of about 1.49 and 1.53 respectively. On the other hand styrene and polycarbonate behave more like flints (with abbe values in the low to mid-30s) and having an index of refraction of about 1.59.

2.2.1.3 Transition Temperature, Coefficient of Thermal Expansion, H2O uptake, and dn/dt

When compared to glass, plastics have a much lower transition temperature (it's not unusual to see maximum continuous service temperatures of under 130-degrees C.) They also have a much higher coefficient of linear expansion (about an order of magnitude higher). Plastics will exhibit a change in index of refraction relative to temperature; the thermoplastic dn/dt is fairly large (about 20 times that of glass) and negative[1]. Most thermoplastics (with the exception of COP and COC materials) will absorb water, which will cause the lens shape to change dimensionally. For example, acrylic will absorb approximately 0.3% water over a 24-hr period. During the same period, a COP or COC material may absorb only 0.01%.

Plastic generally is lighter in weight than glass, so depending on the glass type alternative, using a polymer optic can significantly reduce the weight in a system. Finally, it should be noted that polymers are not nearly as hard as glass. Many different scales are used to measure hardness. One scale that is readily grasped is Moh's ordinal scale of mineral hardness. With talc at the softest (1) and diamond at the top of the scale (10), most plastics come in at around 2 (absolute hardness of about 3), equal to gypsum. It is clear that polymer optics must be protected in whatever system they are used.

2.2.2 Molds

The mold used to manufacture polymer optics can be thought of as a sophisticated three dimensional steel puzzle that has two main features: (1) the cavity details along with the core pins (also known as optical inserts or nubbins), and (2) the frame (sometimes called the base) that houses the cavities and inserts. The figures below illustrate the basic concept of the mold. The complexity of the mold is a function of the complexity of the element being molded. One of the key advantages of using polymer optics is the ability to combine optical and mechanical features into one platform. So, depending upon the nature of the mechanical features being considered the mold itself can take on additional complexity.

The mold is mounted into the molding press. One side of the mold is mounted to the fixed side of the press; the other side is mounted onto the moveable platen within the press. During the molding process, the two mold halves are clamped together under high pressure. The molten resin is injected into the mold by the press and the melt moves through the channels in the tool to the cavities. The cavities fill with the resin and take on the shape of the cavity detail. Once the plastic has cooled to an appropriate temperature, the mold opens and the optics are removed.

The mold is built to the negative of the final part. Thus if the final optic has a convex surface the optical insert will be concave. The mechanical features of the part have to be drafted (tapered) so that they will not be trapped in the mold after the resin has solidified.

All thermoplastics shrink as they cool. In general, the shrinkage is approximately 0.5% to 0.6%. It is important that the shrinkage be taken into consideration when determining the final dimensions of the mold. If the mold is made to the final drawing specifications the part will be too small. One needs to make the mold wrong, if you will, to make the part right. Usually molds are built steel-safe, which allows mold adjustments to be done by removing steel.

With the advent of sophisticated CNC lathes most optical inserts are diamond turned from nickel-plated steel. This method makes it possible to create on and off axis aspheric surfaces and allows the optical molder the flexibility of adjusting the inserts for shrinkage after initial molding trials have be done.

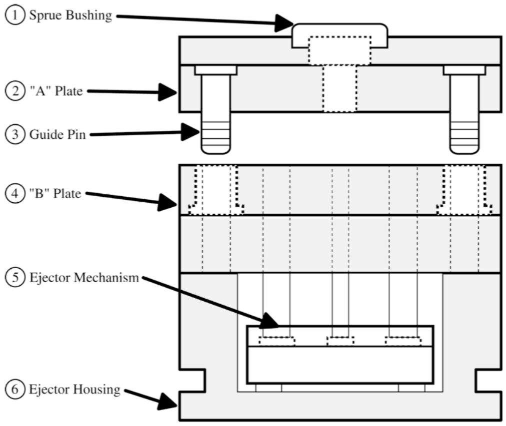


Figure 1. Mold Cross Section

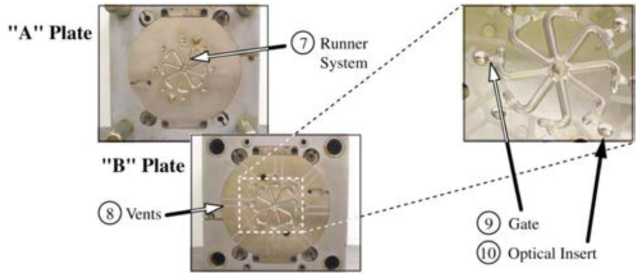


Figure 2. Mold-parting line photos

The following is a brief list of some of the key features generally found in molds along with a brief description of their intended function[2].

1. Sprue Bushing. Provides means of entry into the mold interior.
2. Top (A-side) plate. Portion of the mold mounted on the stationary side of the press.
3. Guide Pins. Maintains proper alignment of the two halves of the mold.
4. Bottom (B-side) plate. Side opposite the “A” side, sits on the moveable platen of the molding press.
5. Ejector Mechanism System. Used to eject rigid molded elements from the cavities.
6. Ejector Housing. Houses the ejector system.
7. Runner System. System of channels in the mold face used to convey molten plastic from the sprue to the cavities.
8. Vents. Structures that allows trapped gas to escape.
9. Gates Region of the mold that controls the flow of molten material into the cavities.
10. Optical inserts (sometimes referred to as nubbins). Pins within the mold that have been deterministically ground and polished against which the optical surface forms during the molding process. These surfaces can be steel or a non-ferrous alloy.

2.2.3 Molding Machines

Molding machines are used to hold the mold and to melt and inject the plastic into the mold. The figure below shows the basic features of a molding machine.

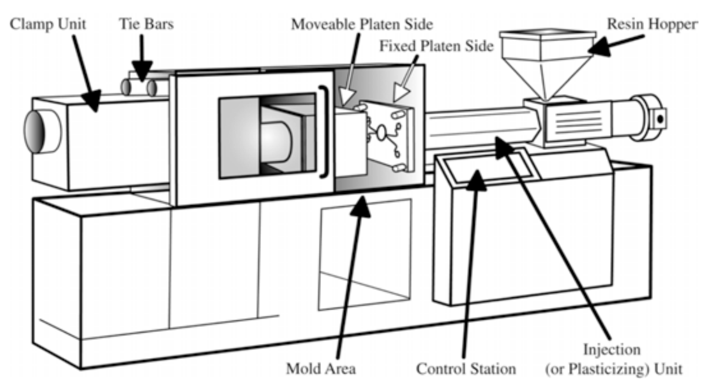


Figure 3. Schematic of a molding press.

The molding press has a clamp unit on one end and the injection unit on the other. The mold is hung in the middle region as shown. The clamp unit is used to keep the two mold halves together as the molten resin is being injected. The molding cycle begins. The moveable platen closes against the fixed platen (closing the mold). An appropriate amount of force is used to hold the mold closed during the injection cycle. The injection unit, consisting of a feed hopper, reciprocating screw, and barrel, picks up an amount of pelletized resin from the hopper. It is the job of the injection unit to melt the resin and to push it into the mold through the sprue bushing. The reciprocating screw turns within the barrel. It is fluted allowing it to trap the material between the heated chamber wall and the screw. The chamber wall is the bearing surface where sheer is applied to the resin as it is being advanced towards the mold. Once the molten material accumulates at the end of the screw it is injected at an appropriate speed and pressure into the mold. This causes the material to flow into the mold to fill the cavities. The molding machine provides complete control over this process, governing the size of the shot, injection speed, injection pressure, backpressure, cushion, and other critical variables that will determine the final outcome of the optic. After an appropriate cooling time, the moveable platen moves away from the fixed platen, and the mold opens. This allows the optics (still attached to the runner system) to be removed. After the shot is removed, the cycle starts over again.

Other equipment is often found along side the molding machine. For parts that require a large amount of material, auto loading hoppers are used to feed material into the machine. Also, the thermoplastics must be dried before being fed into the injection unit. It is common to see desiccating equipment located near the press for this purpose. Once the molding cycle is completed it is desirable to promptly remove the shot so that the entire molding process may be repeated with regularity. To aide in this, a robotic arm is frequently used to ensure that the removal is done on time. This enables the entire process to go into a steady state. Depending on the nature of the program, additional automation or end of arm tooling may be required to remove of the parts from the press, degate them from the runner, and package them into trays for final shipment. Degating is the process whereby the optical elements themselves are removed from the runner system.

3. TYING IT ALL TOGETHER

As noted above, it is important that the designer has a basic understanding of the manufacturing process and of the limits of size and tolerances that might be expected of the finished optics. In general terms, overall shape and tolerances of the optic will drive cost and manufacturability. There are some general guidelines: thicker parts take longer to mold than thinner parts. Optics with extremely thick centers and thin edges are very challenging to mold. Negative optics (thin centers with heavy edges) are difficult to mold. Optics with very tight tolerances may not be manufacturable at all in a one cavity mold, much less in a mold with more than one cavity. There are some other general tolerances that can describe the limits of fabrication in an ideally designed optic.

Attribute	**Rules of Thumb Tolerances**
Radius of Curvature	± 0.50%
EFL	± 1.0%
Center Thickness	± 0.020mm
Diameter	± 0.020mm
Wedge (TIR) in the Element	< 0.010mm
S1 to S2 Displacement (across the parting line)	< 0.020mm
Surface Figure Error	≤ 2 fringes per 25.4mm (2 fringes = 1 wave @ 632nm)
Surface Irregularity	≤ 1 fringes per 25.4mm (2 fringes = 1 wave @ 632nm)
Scratch-Dig Specification	40-20
Surface Roughness (RMS)	≤ 100 Å
Diameter to Center Thickness Ratio	< 4:1
Center Thickness to Edge Thickness Ratio	< 3:1
Part to Part Repeatability (in a one cavity mold)	< 0.50%

Table 2. Rules of thumb.

Two things should be observed here. (1) Even with the rules of thumb, it is very difficult for the experienced optical molder to communicate all of the things that the designer should look out for. There are simply too many variables to consider without expert guidance. In this regard we might say it is not unlike consulting with a doctor on a medical issue or with a lawyer on a legal matter. One might have a general idea of the issues from one's own reading or researching on the internet; however, expert assistance is needed to answer deeper questions. And (2), what is not discussed here is how the rules of thumb interact with one another or how a change in one area will impact another. Rules of thumb are quick generalizations. They are useful for initial discussions, but the rules can quickly break down as the limits of size, shape, thickness, materials, and tolerances are encountered. It is impossible to publish an exhaustive list of possible interactions between all of these variables. The main reason for consulting with the optical molder is that a good optical molder will bring years of experience to the table.

What is the best way for the designer to work with an optical molder? Perhaps the best way is to proceed from a systems design perspective. Instead of communicating with the optical molder at arms length with a drawing and tolerances hoping for the right solution, instead, why not communicate the big picture to the molder so that they can help address questions that may not even be in view at the component drawing level. Perhaps the best way to grasp this is to consider an example.

3.1 Example 1. The effect of design on cycle time and total cost of acquisition

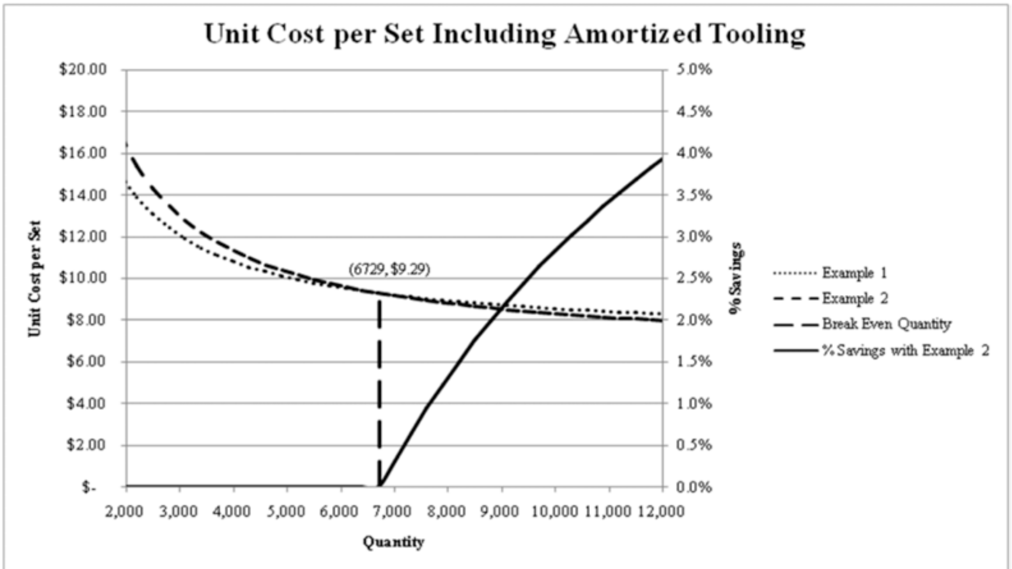
The optical molder received the following request for quotation. The element is acrylic, bi-convex, aspheric on both surfaces, 75mm in diameter ± 0.050mm, with a 12mm center thickness and a 2mm edge thickness, both toleranced at ± 0.020mm. The clear aperture extends to within 2 mm of the edge. Power and irregularity are specified at 5 fringes and 10 fringes respectively. The lens has a S1 to S2 displacement tolerance of ± 0.020mm. The drawing has no provisions for a gate location. Volumes are 10,000 pieces per year. Please quote.

A lens with this description is going to be very expensive. If we use an overhead rate of \$120/hr[3], and an estimated cycle time of 6 minutes, we would have a lens that costs about \$12.00. The tight tolerances would likely increase scrap, so accounting for yield loss would push the price higher to around \$14.00. To mitigate this increase, a typical tactic would be to build a higher cavitation tool, but because of the tight tolerances, this lens could never be run in a multi-cavity mold. Cavity to cavity variation would increase the power and irregularity errors to a point where not every cavity would meet the specification. There is no way to achieve the economies of scale that can be realized by going to higher cavitation. If we say that the mold for this lens would cost about \$15,000, the total cost of acquisition for the first year production would be about \$15.50/lens.

3.2 Example 2. How a manufacturable design can reduce the total cost of acquisition

An alternative approach to example 1 is to look at the system design with guidance from an optical molder, who may ask the question: can this thick optic be split into two thinner optics? If the system design were flexible enough to allow a two lens solution, then we might see an alternative scenario where two lenses with 3 minute cycle times can reduce the total cost of ownership through yield improvements (assuming the two separate lenses have more achievable tolerances, which is very likely).

The tooling cost for the two-lens solution, which would involve building one mold with two cavities that can be run independently, would be about \$20,000 – a \$5,000 increase over example 1. The graph below, which plots the unit cost of examples 1 and 2 (a set of two parts) including amortized tooling, shows that the improvement in yield gained through a more manufacturable design results in a breakeven point of around 6,700 pieces. From a cost perspective, if more than 6,700 pieces are required, it becomes cheaper to have a two lens solution. This savings could increase if the cycle time for either lens is less than 3 minutes (which is likely).



Graph 2. Unit cost per set with tooling amortized.

The economics work out, but the hidden cost of the risk between examples 1 and 2 is not captured. On paper example 1 is more challenging to manufacture and may lead to unexpected manufacturability issues. A competent optical molder would identify those issues as potential red flags so that contingencies can be determined upfront. For example, the power and irregularity tolerances are very difficult, and the parts may only barely meet the specification. What is the impact to the system if these values exceed the spec? Will it degrade performance? What if the tolerance analysis is incorrect and the specs need to be tighter, but that is only discovered after parts have been molded and tested? These are a few of the questions an optical molder must consider. Example 2 is expected to have looser tolerances, so many of the above concerns are inherently less risky.

The inquiry in example one called for an annual volume of 10,000 pieces. If the company has success selling the product, the volumes may go up and create a capacity constraint or lower cost requirement. A mold can only produce a certain number of pieces per year (around 35,000 pieces for one shift in example 1), and the cost is primarily cycle time driven. Since multi-cavity tools help to address both concerns, it is important to consider at the beginning if the lens can be made in a mold that has more than one-cavity. In example one above, the answer is no. The tolerances are too tight. In contrast example two has the benefit of looser tolerances and thinner optics, both of which bode well for the ability to expand to multiple cavities. The need to act on higher cavitation tooling may be delayed due to the higher production capacity of the 1-cavity molds (due to shorter cycle times), but having flexibility in the decision making process is often beneficial.

In much the same way that future expectations of multi-cavity molds must be considered upfront, the need for and method of prototyping must be mindful of future production methods and requirements. Prototypes are often used to provide functional devices to evaluate customer demand and market opportunities, but sometimes they are produced to prove that the system will work. Diamond turning is the most direct way of producing prototypes, and the achieved tolerances are typically much less than the specification limits. This is both a blessing and a curse, since the end result of the prototyping process may verify that a design is functional without testing the tolerance limits. Understanding the differences between what is achievable with prototypes (via diamond turning or prototype molding) versus volume production is crucial to making sure a design is production capable. The experienced optical molder can help a designer navigate through these potential pitfalls.

Other system design factors come into play as well. The temptation is to consider these as mundane non-optical issues, however, if not addressed correctly these issues can add considerably to the total cost of acquisition. For example, where will the lens be gated? Can the mating part be adjusted so that a longer gate vestige can be accommodated? How

will the part be packaged? How will the part be handled? Does the optic need some kind of keying feature to help with down the road assembly? The answers to these questions can add additional and sometimes significant cost to the final component.

There are other things to consider: As the design deviates from a conventional on-axis rotationally symmetric optic, measuring the part to verify conformance can become a limiting factor. Interferometers are typically used to measure flat and spherical surfaces, and contact profilometers are proficient at measuring aspheres. For bi-conic, freeform, or off-axis surfaces, a combination of profilometry and CMM (contour measuring machine) inspection can answer many inspection questions. There are instances, though, where the design requires an optic be inspected to a level beyond which these tools are capable. Functional testers and customized inspection setups can often close the gap, but identifying that a gap exists early on in the design process is critical for finding a solution.

The point here is that the lens designer may not be thinking of these things when presenting a drawing for bid. He may not even be aware that there are larger issues like this to consider. He is probably concentrating on how the lens needs to perform in the system and rightly so. But the lens does not exist in isolation. The rest of the system, along with the commercial aspects of future production needs, should be addressed up front so that the appropriate tooling set can be accounted for. These are the things that the layman may not know that he doesn't know.

Finally, similar to how it is impossible for a designer to work from an exhaustive list of optical molding rules, there are other critical to success aspects of the manufacturing process that the molder does not know either. This is where the molder's supplier network comes into play. The tooling supplier identifies risks and makes suggestions about the mold in a back and forth process similar to how the molder works with the designer/customer. The same is true about coating, diamond turning, or other processes that are needed to make or support the production of the part. As an extension of this, it is beneficial for the molder to know many of these things first hand so that as many requirements can be determined in the one-on-one discussions with the customer. Finding a molder that has internal capability for diamond turning, coating, automation, fixturing, and so forth, will help to streamline the process, manage cost, and improve quality.

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(12) **United States Patent**
Chen et al.

(10) **Patent No.: US 7,777,972 B1**
(45) **Date of Patent: Aug. 17, 2010**

(54) **IMAGING OPTICAL LENS ASSEMBLY**

(75) Inventors: **Chun-Shan Chen**, Taichung (TW); **Hsiang-Chi Tang**, Taichung (TW)

(73) Assignee: **Largan Precision Co., Ltd.**, Taichung (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/483,748**

(22) Filed: **Jun. 12, 2009**

(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
G02B 9/34 (2006.01)
G02B 13/18 (2006.01)

(52) **U.S. Cl.** **359/773**; 359/715; 359/740

(58) **Field of Classification Search** 359/715, 359/738, 740, 773
See application file for complete search history.

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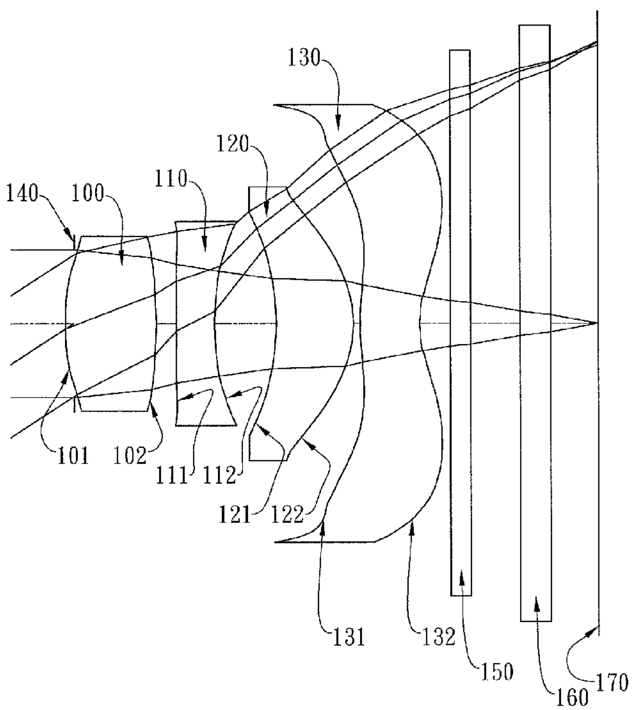
Primary Examiner—Evelyn A. Lester
(74) *Attorney, Agent, or Firm*—Birch, Stewart, Kolasch & Birch, LLP

(57) **ABSTRACT**

The present invention provides an imaging optical lens assembly including, in order from the object side to the image side: a first lens group comprising a first lens element with positive refractive power, no lens element with refractive power being disposed between the first lens element and an imaged object, the first lens element being the only lens element with refractive power in the first lens group; and a second lens group comprising, in order from the object side to the image side: a second lens element with negative refractive power; a third lens element; and a fourth lens element; wherein focusing adjustment is performed by moving the first lens element along an optical axis, such that as a distance between the imaged object and the imaging optical lens assembly changes from far to near, a distance between the first lens element and an image plane changes from near to far; and wherein the number of the lens elements with refractive power in the imaging optical lens assembly is N, and it satisfies the relation: $4 \leqq N \leqq 5$. The abovementioned arrangement of optical elements and focusing adjustment method enable the imaging optical lens assembly to obtain good image quality and consume less power.

19 Claims, 16 Drawing Sheets



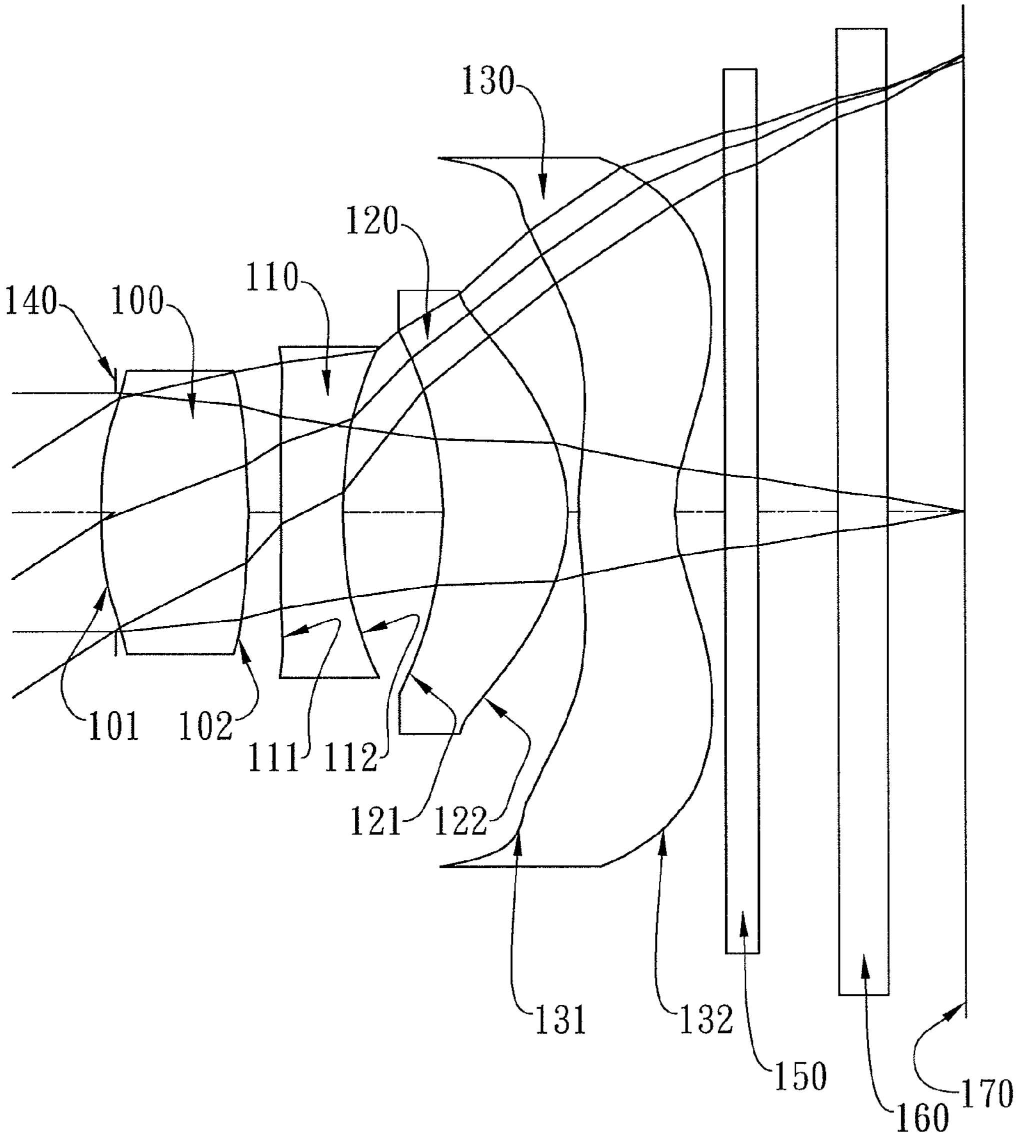
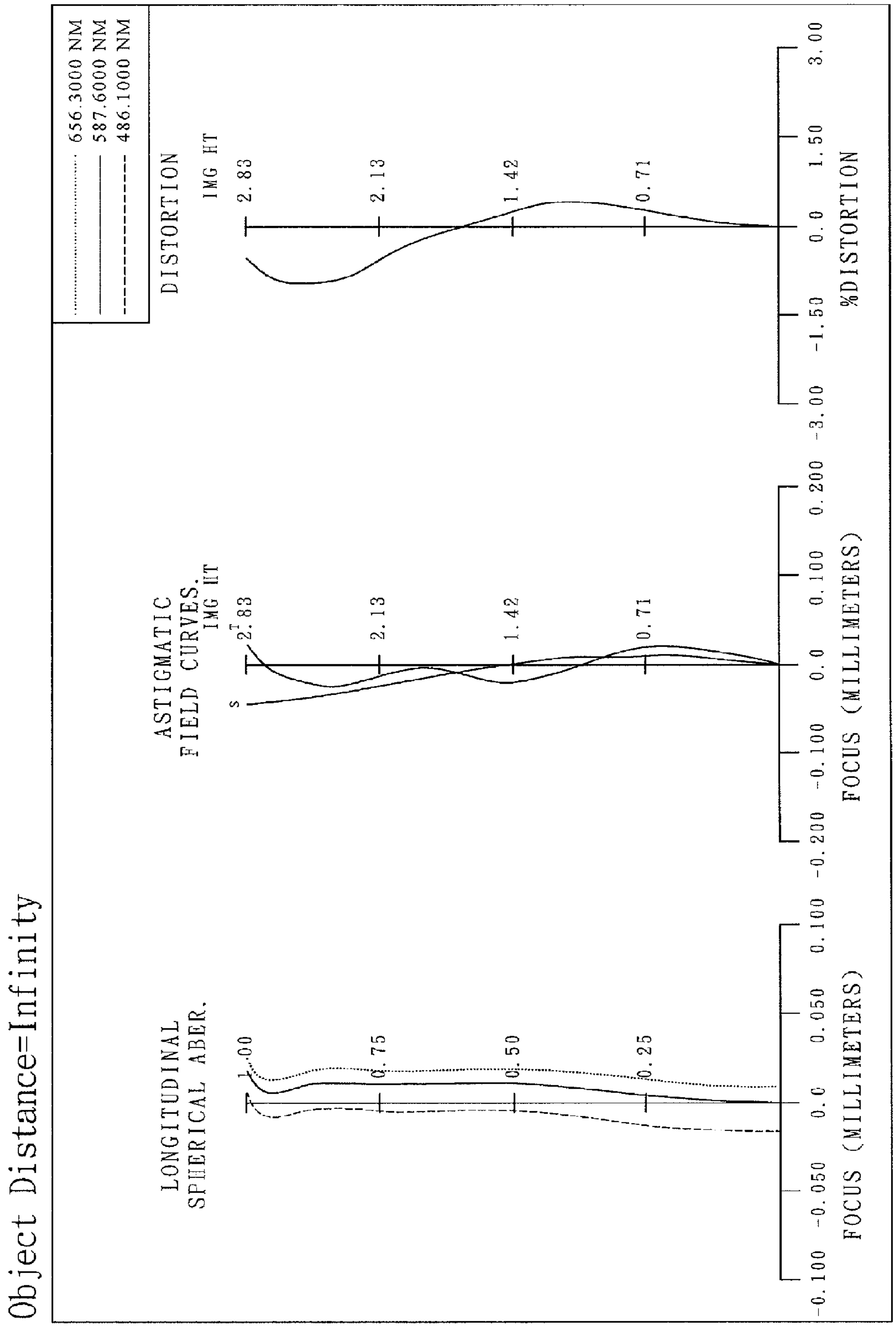


Fig. 1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0.050
0.100
FOCUS (MILLIMETERS)
ASTIGMATIC FIELD CURVES.
IMG HT
T
S
2.83
2.13
1.42
0.71
-0.200
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0.100
0.200
FOCUS (MILLIMETERS)
DISTORTION
IMG HT
2.83
2.13
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1.50
3.00
%DISTORTION

Fig. 2A

Object Distance=100mm

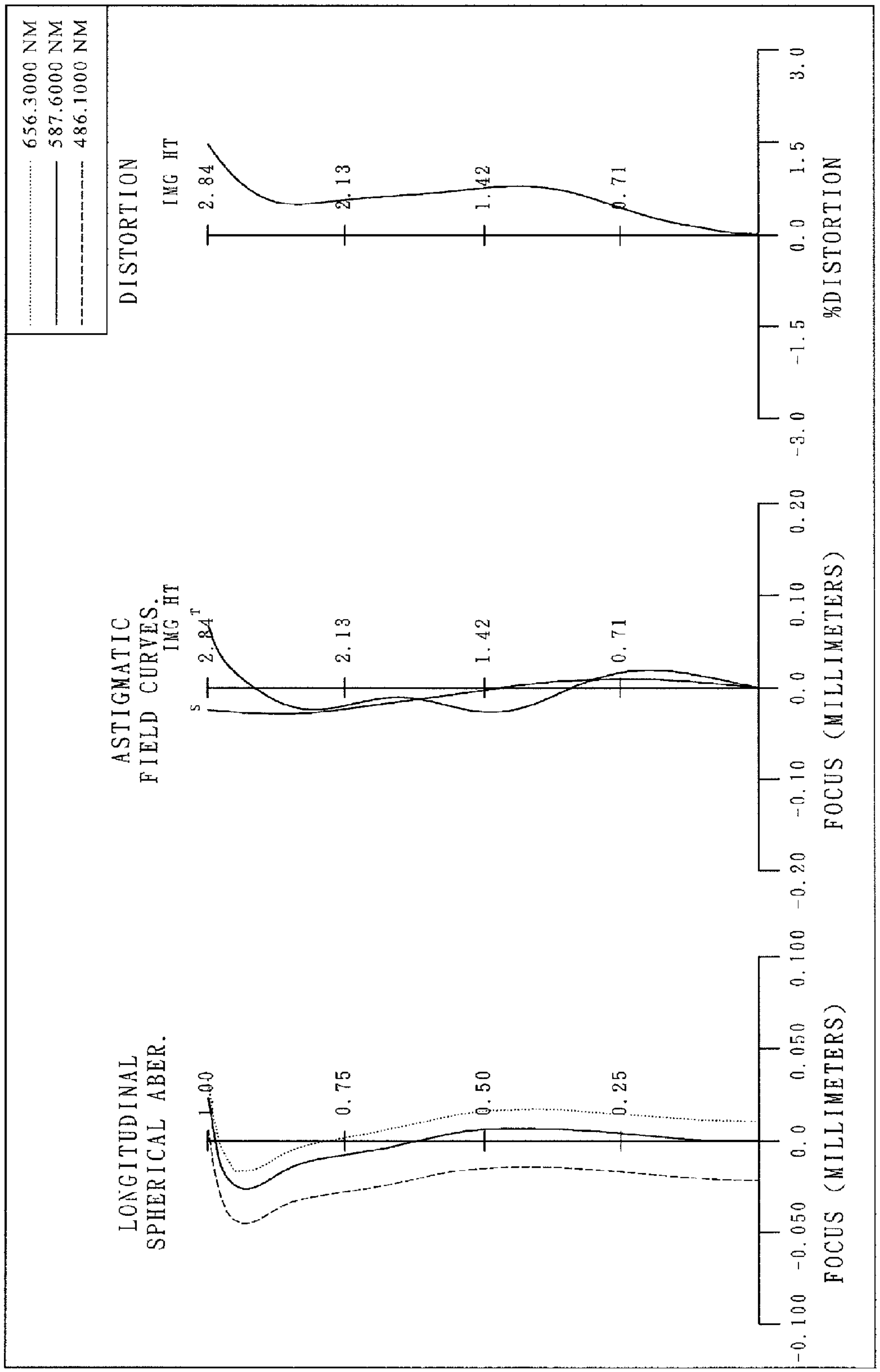


Fig. 2B

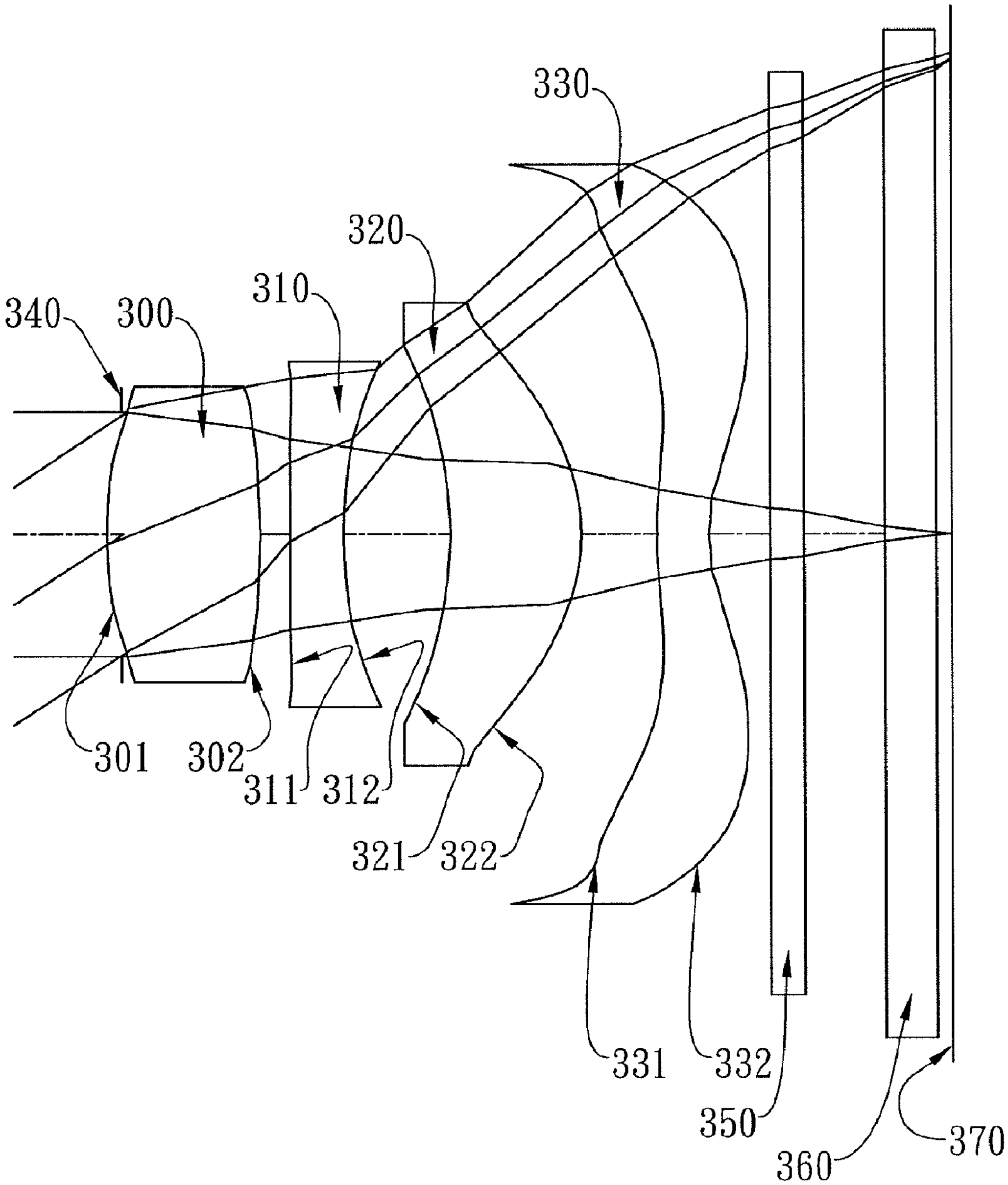
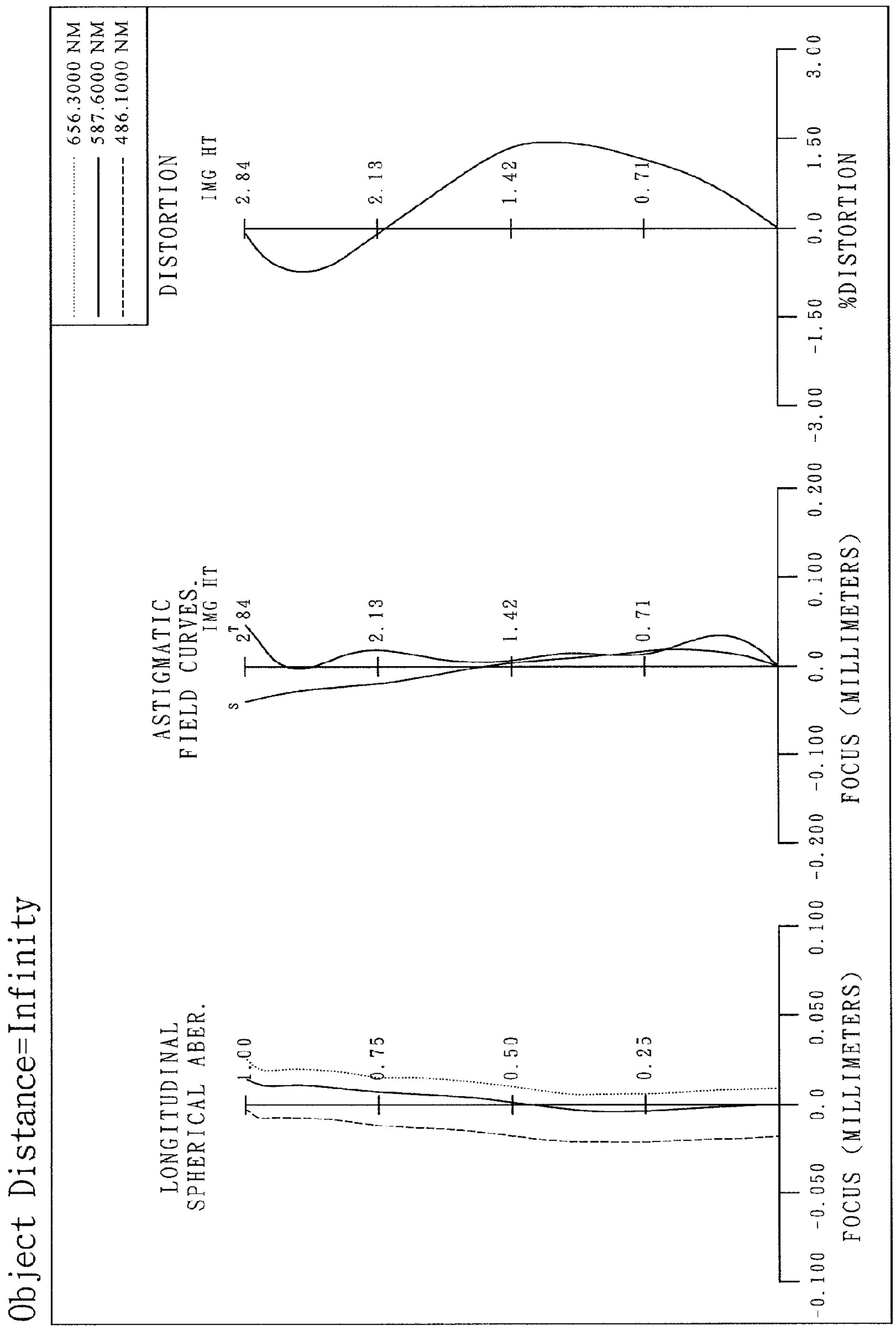


Fig. 3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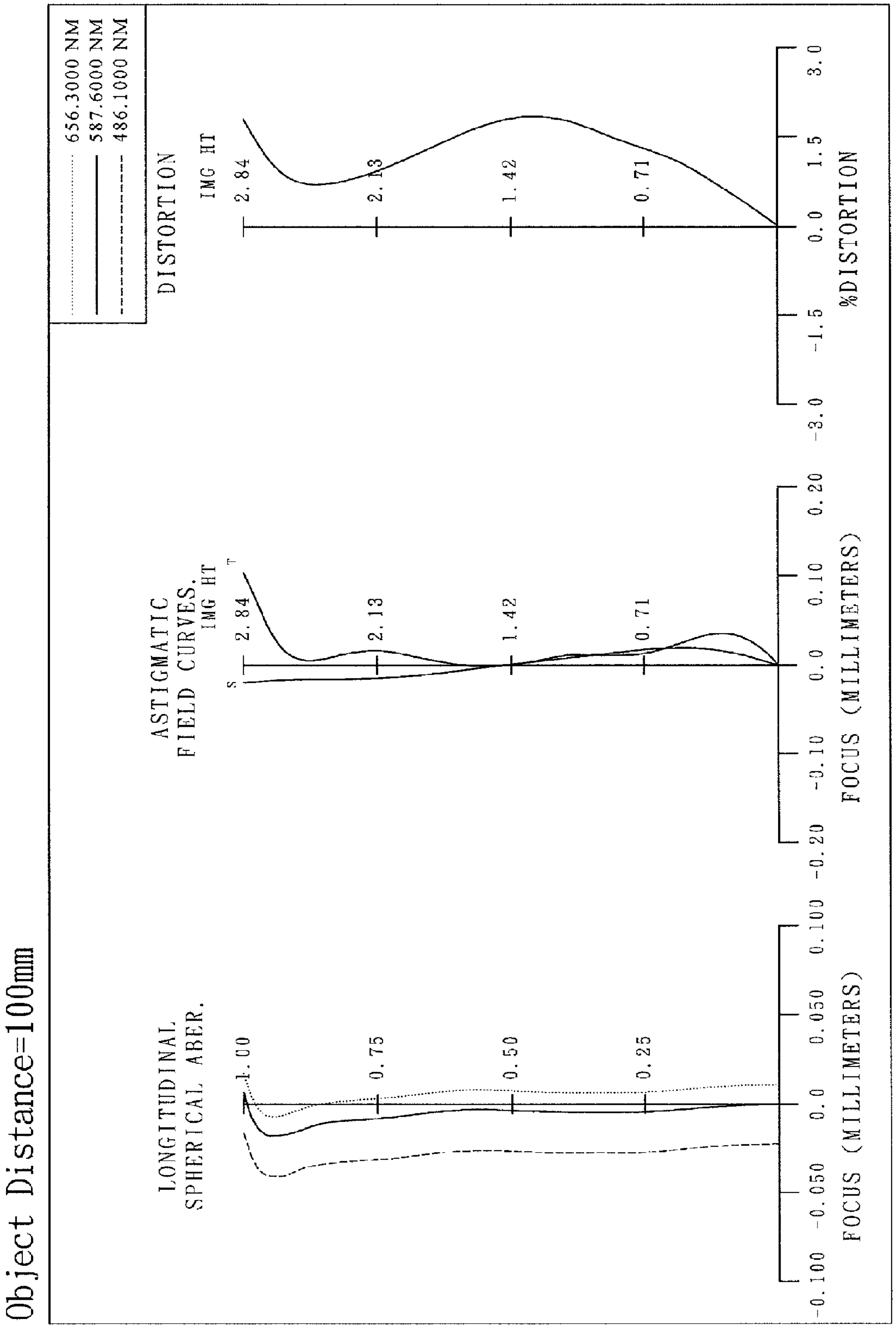
FOCUS (MILLIMETERS)
ASTIGMATIC FIELD CURVES.
IMG HT
2.84
2.13
1.42
0.71
T
S
-0.200 -0.100 0.0 0.100 0.200
FOCUS (MILLIMETERS)
DISTORTION
IMG HT
2.84
2.13
1.42
0.71
-3.00 -1.50 0.0 1.50 3.00
%DISTORTION

Fig. 4A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-0.050
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0.050
0.100
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2.84
2.13
1.42
0.71
T
S
-0.20
-0.10
0.0
0.10
0.20
FOCUS (MILLIMETERS)
DISTORTION
IMG HT
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0.71
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-1.5
0.0
1.5
3.0
%DISTORTION

Fig. 4B

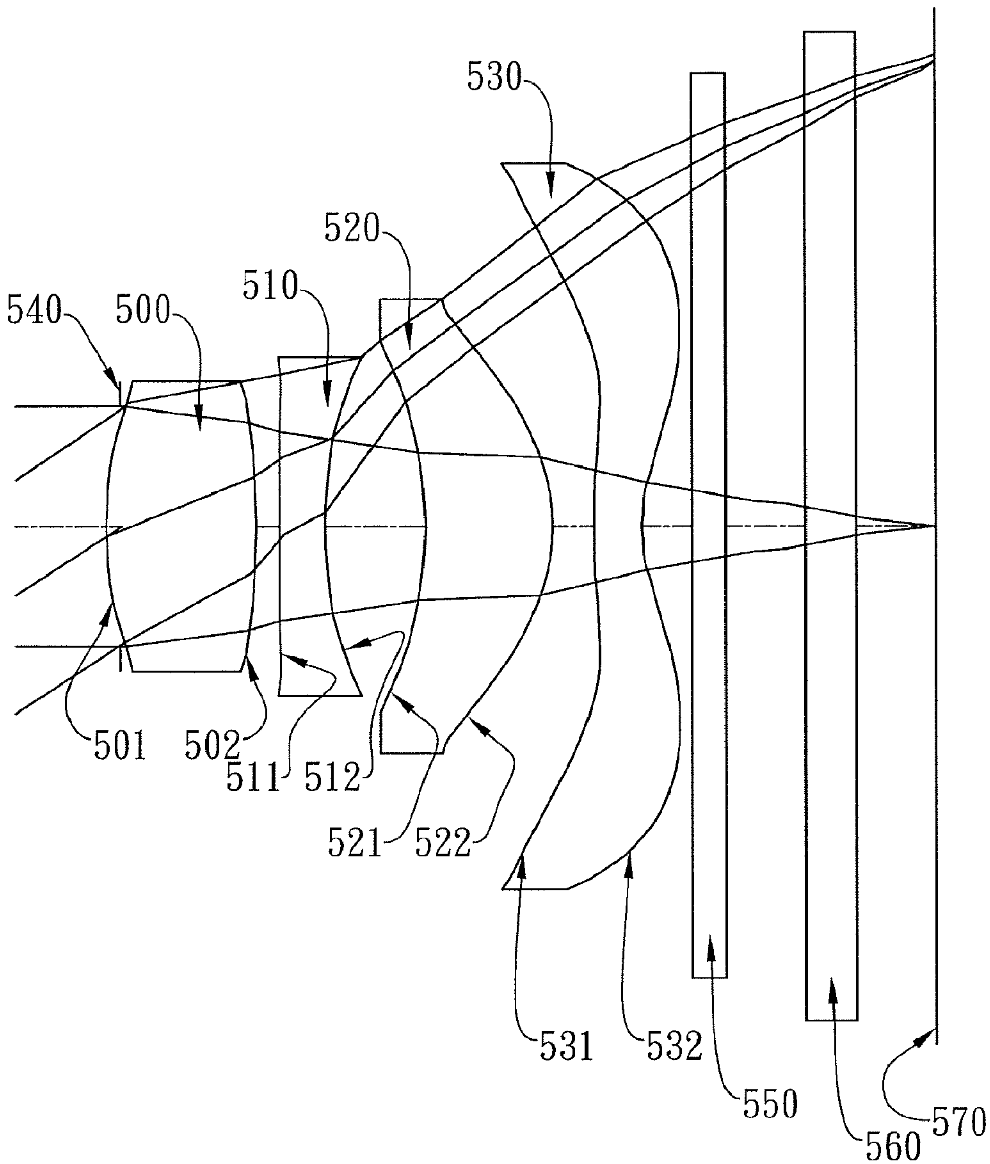
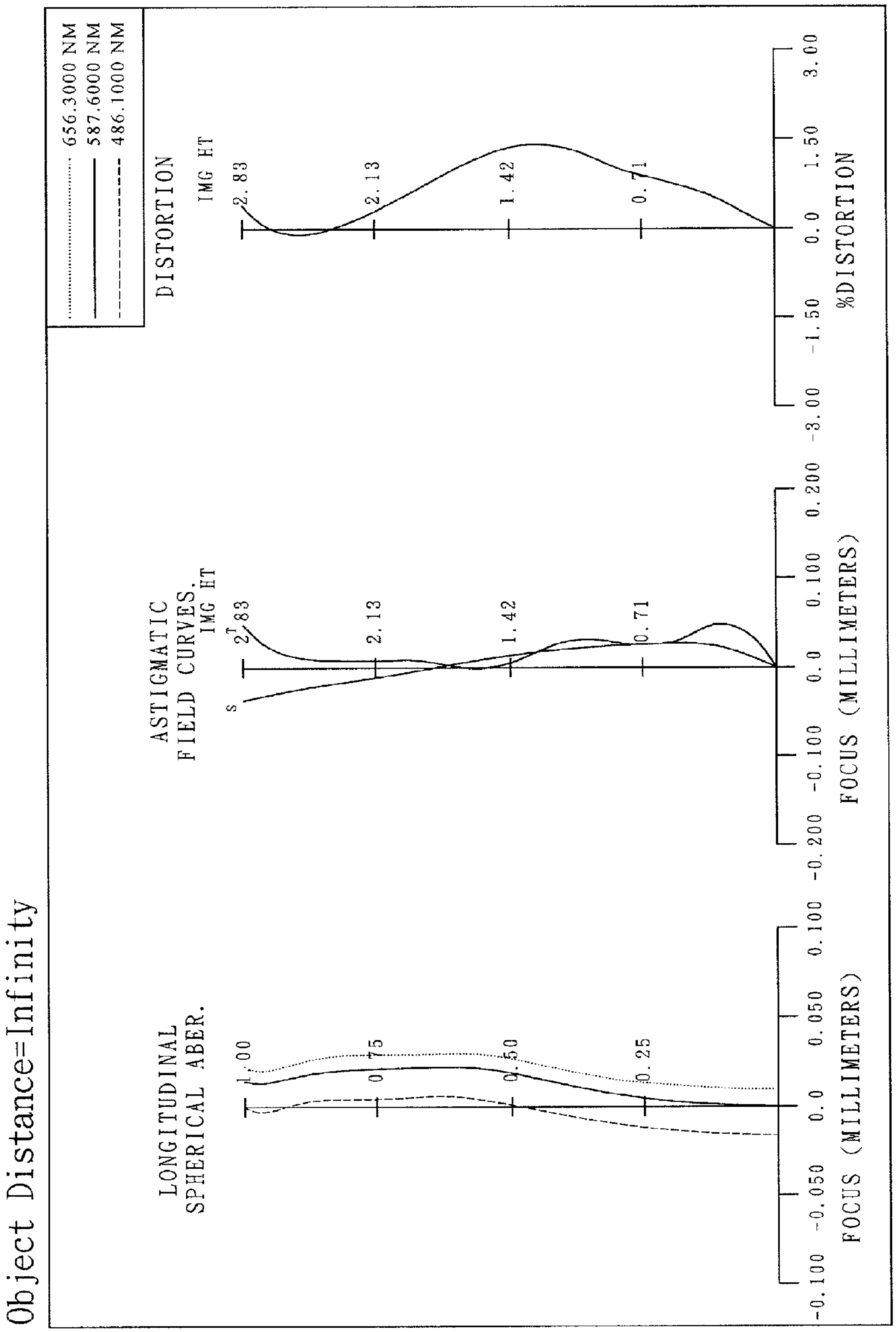


Fig. 5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486.1000 NM
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0.50
0.25
-0.100 -0.050 0.0 0.050 0.100
FOCUS (MILLIMETERS)
ASTIGMATIC FIELD CURVES.
IMG HT
2.83
2.13
1.42
0.71
T
S
-0.200 -0.100 0.0 0.100 0.200
FOCUS (MILLIMETERS)
DISTORTION
IMG HT
2.83
2.13
1.42
0.71
-3.00 -1.50 0.0 1.50 3.00
%DISTORTION

Fig. 6A

Object Distance=100mm

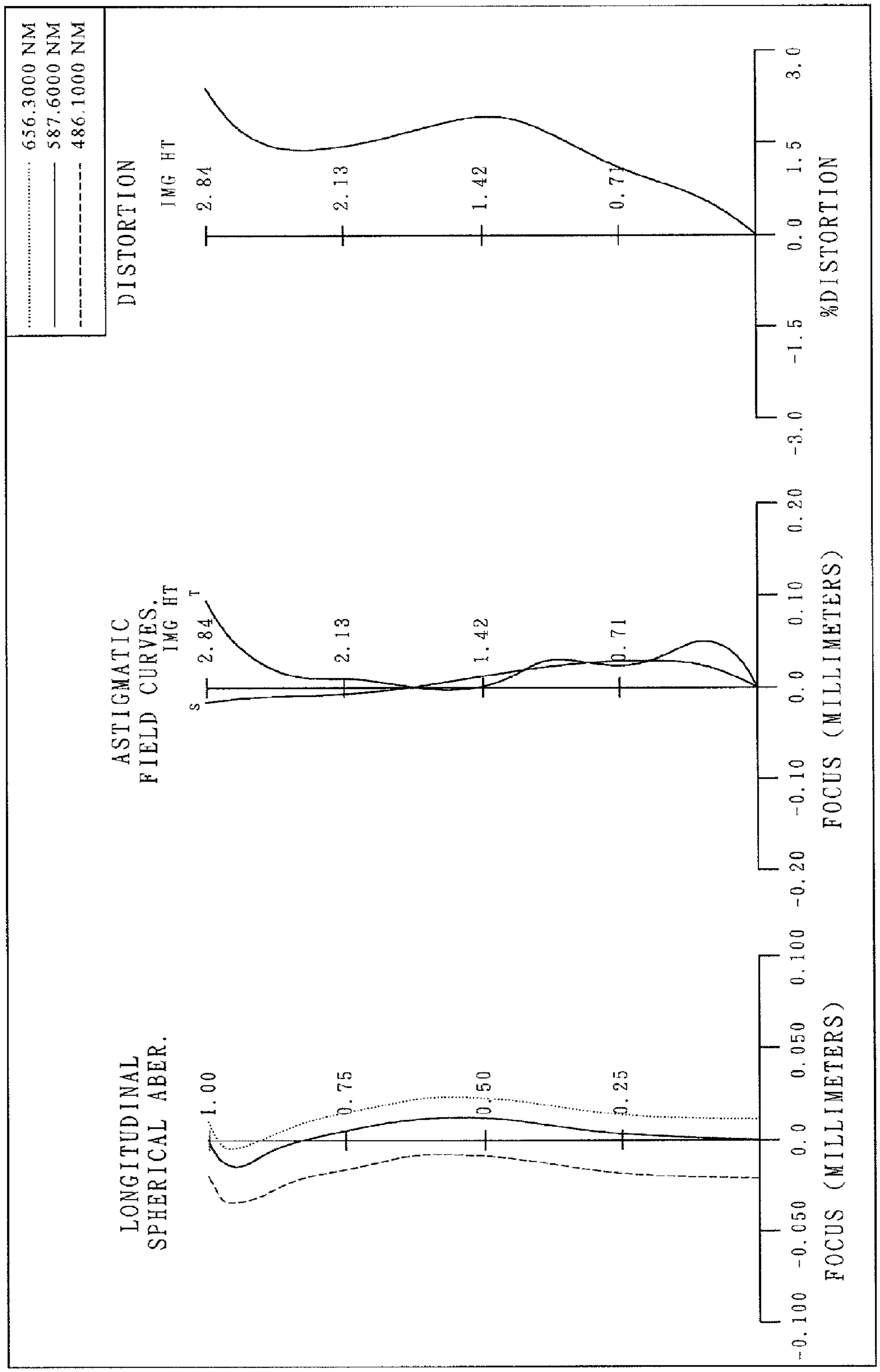

Fig. 6B

TABLE 1

(Embodiment 1)

f = 4.33 mm, Fno = 2.90, HFOV = 33.5 deg.

Surface #		Curvature Radius	Thickness	Material	Index	Abbe #	Focal length
0	Object	Plano	Infinity				
1	Ape. Stop	Plano	-0.089				
2	Lens 1	2.16949 (ASP)	0.900	Plastic	1.544	55.9	3.03
3		-5.88250 (ASP)	0.200				
4	Lens 2	100.00000 (ASP)	0.383	Plastic	1.632	23.4	-5.27
5		3.21670 (ASP)	0.614				
6	Lens 3	-2.18540 (ASP)	0.766	Plastic	1.530	55.8	3.05
7		-1.04238 (ASP)	0.070				
8	Lens 4	2.90877 (ASP)	0.581	Plastic	1.530	55.8	-3.05
9		0.96623 (ASP)	0.300				
10	IR-filter	Plano	0.200	Glass	1.517	64.2	-
11		Plano	0.500				
12	Cover Glass	Plano	0.300	Glass	1.517	64.2	-
13		Plano	0.484				
14	Image	Plano					

*Object Distance 100 mm: surface 3 thickness = 0.287 mm, f = 4.23 mm

Fig.7

TABLE 2

Aspheric Coefficients

Surface #	2	3	4	5
k =	-6.42322E+00	0.00000E+00	-1.00000E+03	-1.63883E+01
A4 =	5.41140E-02	-1.09227E-02	6.01150E-02	1.56920E-01
A6 =	-1.96445E-02	-5.15556E-02	-1.82457E-01	-1.94068E-01
A8 =	-1.14833E-01	2.49347E-02	2.74168E-01	2.21172E-01
A10 =	7.09572E-01	2.44208E-02	-1.16446E-01	-1.06404E-01
A12 =	-2.32230E+00	-4.66235E-02	-2.68287E-01	-4.40642E-02
A14 =	3.54279E+00	-3.82606E-04	4.12009E-01	8.18527E-02
A16=	-2.03569E+00		-1.82905E-01	-2.86683E-02
Surface #	**6**	**7**	**8**	**9**
k =	-2.29304E+01	-4.53794E+00	-3.30328E+00	-5.73407E+00
A4 =	-1.16793E-01	-1.19883E-01	-2.18847E-01	-1.13293E-01
A6 =	1.94942E-01	3.58178E-02	7.07747E-02	4.13104E-02
A8 =	-3.69015E-01	3.08158E-03	-4.89029E-03	-1.28908E-02
A10=	2.56431E-01	-2.21268E-02	-2.89861E-03	2.95065E-03
A12 =	5.95191E-02	1.13277E-02	3.46094E-04	-5.61966E-04
A14=	-1.65957E-01	1.86502E-03	1.72668E-04	7.44048E-05
A16=	6.38640E-02	-9.98190E-04	-3.06196E-05	-4.89505E-06

Fig.8

TABLE 3

(Embodiment 2)

f = 4.25 mm, Fno = 2.90, HFOV = 33.5 deg.

Surface #		Curvature Radius	Thickness	Material	Index	Abbe #	Focal length
0	Object	Plano	Infinity				
1	Ape. Stop	Plano	-0.102				
2	Lens 1	1.89503 (ASP)	0.900	Plastic	1.544	55.9	2.99
3		-9.59770 (ASP)	0.200				
4	Lens 2	-21.59870 (ASP)	0.346	Plastic	1.632	23.4	-5.33
5		4.01330 (ASP)	0.504				
6	Lens 3	-3.30370 (ASP)	0.761	Plastic	1.544	55.9	4.70
7		-1.55897 (ASP)	0.600				
8	Lens 4	2.57806 (ASP)	0.350	Plastic	1.530	55.8	-3.97
9		1.10343 (ASP)	0.300				
10	IR-filter	Plano	0.200	Glass	1.517	64.2	-
11		Plano	0.500				
12	Cover Glass	Plano	0.300	Glass	1.517	64.2	-
13		Plano	0.089				
14	Image	Plano					

*Object Distance 100 mm: surface 3 thickness = 0.283 mm, f = 4.36 mm

Fig.9

TABLE 4

Aspheric Coefficients				
Surface #	2	3	4	5
k =	-3.87349E+00	0.00000E+00	1.25366E+02	-3.52526E+01
A4 =	6.32581E-02	5.09665E-03	8.43181E-02	1.78238E-01
A6 =	-4.00870E-02	-4.18441E-02	-1.59342E-01	-1.84920E-01
A8 =	-5.03443E-02	3.35220E-02	2.35534E-01	2.13392E-01
A10 =	7.64212E-01	-2.23277E-02	-1.18827E-01	-1.04308E-01
A12 =	-2.58608E+00	8.22940E-03	-2.49182E-01	-4.03773E-02
A14 =	3.71028E+00	-2.02587E-02	4.34601E-01	8.43271E-02
A16=	-1.98186E+00		-2.09716E-01	-3.19236E-02
Surface #	6	7	8	9
k =	-6.08404E+01	-3.51853E+00	-6.80667E+01	-7.60755E+00
A4 =	-1.90860E-01	-9.19376E-02	-2.22385E-01	-1.25750E-01
A6 =	2.58744E-01	2.04732E-02	7.47643E-02	4.71329E-02
A8 =	-3.73925E-01	5.82878E-03	-4.26188E-03	-1.49248E-02
A10=	2.46479E-01	-1.72439E-02	-3.05562E-03	3.37376E-03
A12 =	6.78949E-02	1.26764E-02	2.69255E-04	-5.75776E-04
A14=	-1.56664E-01	1.56195E-03	1.64291E-04	6.22629E-05
A16=	5.48830E-02	-1.71070E-03	-2.55825E-05	-3.47004E-06

Fig.10

TABLE 5

(Embodiment 3)

f = 4.23 mm, Fno = 2.90, HFOV = 33.5 deg.

Surface #		Curvature Radius	Thickness	Material	Index	Abbe #	Focal length
0	Object	Plano	Infinity				
1	Ape. Stop	Plano	-0.102				
2	Lens 1	1.83571 (ASP)	0.900	Plastic	1.544	55.9	2.90
3		-9.26100 (ASP)	0.200				
4	Lens 2	-6.73390 (ASP)	0.311	Plastic	1.632	23.4	-5.06
5		6.20280 (ASP)	0.555				
6	Lens 3	-2.41850 (ASP)	0.736	Plastic	1.544	55.9	3.22
7		-1.12530 (ASP)	0.261				
8	Lens 4	1.90758 (ASP)	0.320	Plastic	1.544	55.9	-3.16
9		0.85107 (ASP)	0.300				
10	IR-filter	Plano	0.200	Glass	1.517	64.2	-
11		Plano	0.500				
12	Cover Glass	Plano	0.300	Glass	1.517	64.2	-
13		Plano	0.474				
14	Image	Plano					

*Object Distance 100 mm: surface 3 thickness = 0.278 mm, f = 4.35 mm

Fig.11

TABLE 6

Aspheric Coefficients				
Surface #	2	3	4	5
k =	-3.68354E+00	4.27537E-01	-1.18048E+02	-4.86168E+01
A4 =	6.60970E-02	4.25004E-03	8.41135E-02	1.87208E-01
A6 =	-3.92891E-02	-4.02627E-02	-1.61690E-01	-1.84789E-01
A8 =	-5.48599E-02	3.32827E-02	2.46696E-01	2.09987E-01
A10 =	7.67707E-01	-2.18444E-02	-1.10007E-01	-1.00444E-01
A12 =	-2.57677E+00	9.96757E-03	-2.51777E-01	-3.29311E-02
A14 =	3.69371E+00	-3.24649E-02	4.19955E-01	8.88264E-02
A16=	-1.98154E+00	-3.55830E-04	-2.15316E-01	-4.33497E-02
Surface #	6	7	8	9
k =	-3.22944E+01	-3.25133E+00	-4.08630E+01	-6.51806E+00
A4 =	-2.08072E-01	-9.36284E-02	-2.08003E-01	-1.43476E-01
A6 =	2.67223E-01	1.47155E-02	7.38545E-02	5.61405E-02
A8 =	-3.84575E-01	5.87603E-03	-4.41204E-03	-1.67975E-02
A10=	2.37336E-01	-1.59335E-02	-3.08231E-03	3.32273E-03
A12 =	6.76477E-02	1.30256E-02	2.62777E-04	-5.28673E-04
A14=	-1.53505E-01	1.56088E-03	1.63916E-04	6.68925E-05
A16=	5.58447E-02	-1.82229E-03	-2.51552E-05	-5.25040E-06

Fig.12

TABLE 7

	Embodiment 1	Embodiment 2	Embodiment 3
f	4.33	4.25	4.23
Fno	2.90	2.90	2.90
HFOV	33.5	33.5	33.5
N	4	4	4
fmax/fmin	1.02	1.03	1.03
|BFL1-BFL2|	0.0	0.0	0.0
(D1-D2)*100/f	2.02	1.98	1.87
V1	55.9	55.9	55.9
V2	23.4	23.4	23.4
f/f1	1.43	1.42	1.46
f/f3	1.42	0.90	1.31
T34/T23	0.11	1.19	0.47
TTL/ImgH	1.84	1.75	1.75

Fig.13

IMAGING OPTICAL LENS ASSEMBLY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an imaging optical lens assembly, and more particularly, to an imaging optical lens assembly with focusing adjustment.

2. Description of the Prior Art

In recent years, with the popularity of camera mobile phones, the demand for compact photographing lenses is increasing, and the sensor of a general photographing camera is none other than CCD (charge coupled device) or CMOS device (Complementary Metal Oxide Semiconductor device). Furthermore, as advanced semiconductor manufacturing technology has allowed the pixel size of sensors to be reduced and compact photographing lenses have gradually evolved toward higher megapixels, there is an increasing demand for compact photographing lenses featuring better image quality.

A conventional compact photographing lens equipped in a mobile phone is usually a single focus lens having a fixed focal length. For a specific object distance, since the photographing lens has a limited depth of field, it is apt to produce blurred images. Therefore, as the resolution of compact photographing lenses increases, a focusing adjustment function becomes more and more indispensable as well. Generally, a photographing lens with focusing adjustment function performs focusing adjustment by using a driving motor to move the entire photographing lens relative to the sensor. However, such a photographing lens requires higher power consumption because the driving motor is configured to drive the entire photographing lens. Moreover, the photographing lens has a relatively long total track length.

SUMMARY OF THE INVENTION

The present invention provides an imaging optical lens assembly including, in order from the object side to the image side: a first lens group comprising a first lens element with positive refractive power, no lens element with refractive power being disposed between the first lens element and an imaged object, the first lens element being the only lens element with refractive power in the first lens group; and a second lens group comprising, in order from the object side to the image side: a second lens element with negative refractive power; a third lens element; and a fourth lens element; focusing is performed by moving the first lens element along the optical axis, such that as a distance between the imaged object and the imaging optical lens assembly changes from far to near, a distance between the first lens element and the imaging surface changes from near to far, and during focusing the other lens elements in the imaging optical lens assembly do not move relative to the imaging plane; and wherein the number of the lens elements with refractive power in the imaging optical lens assembly is N, and it satisfies the relation: $4 \leqq N \leqq 5$.

According to one aspect of the present invention, there is provided a method for performing focusing for an imaging optical lens assembly; wherein the lens assembly includes, in order from the object side to the image side: a first lens group comprising a first lens element with positive refractive power, no lens element with refractive power being disposed between the first lens element and an imaged object, the first lens element being the only lens element with refractive power in the first lens group; and a second lens group comprising, in order from the object side to the image side: a second lens element with negative refractive power; a third lens element; and a fourth lens element; and wherein the method for performing focusing includes moving the first lens element along the optical axis, such that as a distance between the imaged object and the imaging optical lens assembly changes from far to near, a distance between the first lens element and the imaging surface changes from near to far, and during focusing the other lens elements in the imaging optical lens assembly can either move or not move relative to the imaging plane.

The aforementioned arrangement of lens groups can effectively improve the image quality of the imaging optical lens assembly. In the present imaging optical lens assembly, a single lens element, the first lens element, is selected to move along the optical axis to perform the focusing adjustment so that less power will be consumed during the focusing process. In addition, by selecting the first lens element to perform focusing adjustment, the number of lens groups can be reduced to effectively reduce the variability in the assembly/manufacturing of the imaging optical lens assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an imaging optical lens assembly in accordance with a first embodiment of the present invention.

FIG. **2** shows the aberration curves of the first embodiment of the present invention.

FIG. **3** shows an imaging optical lens assembly in accordance with a second embodiment of the present invention.

FIG. **4** shows the aberration curves of the second embodiment of the present invention.

FIG. **5** shows an imaging optical lens assembly in accordance with a third embodiment of the present invention.

FIG. **6** shows the aberration curves of the third embodiment of the present invention.

FIG. **7** is TABLE 1 which lists the optical data of the first embodiment.

FIG. **8** is TABLE 2 which lists the aspheric surface data of the first embodiment.

FIG. **9** is TABLE 3 which lists the optical data of the second embodiment.

FIG. **10** is TABLE 4 which lists the aspheric surface data of the second embodiment.

FIG. **11** is TABLE 5 which lists the optical data of the third embodiment.

FIG. **12** is TABLE 6 which lists the aspheric surface data of the third embodiment.

FIG. **13** is TABLE 7 which lists the data of the respective embodiments resulted from the equations.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides an imaging optical lens assembly including, in order from the object side to the image side: a first lens group comprising a first lens element with positive refractive power, no lens element with refractive power being disposed between the first lens element and an imaged object, the first lens element being the only lens element with refractive power in the first lens group; and a second lens group comprising, in order from the object side to the image side: a second lens element with negative refractive power; a third lens element; and a fourth lens element; wherein focusing is performed by moving the first lens element along the optical axis, such that as a distance between the imaged object and the imaging optical lens assembly changes from far to near, a distance between the first lens

element and the imaging surface changes from near to far; and wherein the number of the lens elements with refractive power in the imaging optical lens assembly is N, and it satisfies the relation: $4 \leqq N \leqq 5$.

When the relation of N=5 is satisfied, the fifth lens element can be disposed between the first and second lens elements, the third and fourth lens elements, or the fourth lens element and the image plane.

In the aforementioned imaging optical lens assembly, the focal length of the imaging optical lens assembly is f when the first lens element is positioned closest to the image plane, the focal length of the first lens element is f1, the focal length of the third lens element is f3, and they satisfy the relations: $1.0<f/f1<1.7$, $0.6<f/f3<1.8$.

When f/f1 satisfies the above relation, the displacement distance of the first lens element will not be too large, thus the total track length (TTL) of the imaging optical lens assembly will not become too long. This also ensures that the movement of the first lens element relative to the image plane has enough sensitivity required for focusing adjustment. By having the first lens element move along the optical axis to perform the focusing adjustment (the so-called internal focusing method), the total track length of the imaging optical lens assembly can be shortened effectively. TTL is defined as the on-axis spacing between the object-side surface of the first lens element and the image plane when the first lens element is positioned closest to the imaged object.

The relation $0.6<f/f3<1.8$ enables the third lens element to effectively distribute the refractive power of the optical system, reducing the sensitivity of the optical system.

In the aforementioned imaging optical lens assembly, the on-axis spacing between the image-side surface of the first lens element and the image plane is D1 when the first lens element is positioned closest to the imaged object, the on-axis spacing between the image-side surface of the first lens element and the image plane is D2 when the first lens element is positioned closest to the image plane, the focal length of the imaging optical lens assembly is f when the first lens element is positioned closest to the image plane, and they satisfy the relation: $1.0<(D1-D2)*100/f<3.0$.

When the above relation is satisfied, the movement of the first lens element relative to the image plane has enough sensitivity required for focusing adjustment. The above relation also prevents the displacement distance of the first lens element from becoming too large.

In the aforementioned imaging optical lens assembly, the on-axis spacing between the third lens element and the fourth lens element is T34, the on-axis spacing between the second lens element and the third lens element is T23, and they satisfy the relation: $0.2<T34/T23<1.6$.

When the above relation is satisfied, the off-axis aberration of the imaging optical lens assembly can be effectively corrected. The above relation also prevents the back focal length from becoming too short and thus causing the rear end of the lens assembly to have insufficient space to accommodate mechanical components.

In the aforementioned imaging optical lens assembly, the maximum focal length of the imaging optical lens assembly is f_{max}, the minimum focal length of the imaging optical lens assembly is f_{min}, and they satisfy the relation: $1 \leqq f_{max}/f_{min} \leqq 1.05$.

The above relation prevents the displacement distance of the first lens element from becoming too large and keeps the magnifying power of the optical system within a proper range.

In the aforementioned imaging optical lens assembly, the back focal length of the imaging optical lens assembly is BFL1 when the first lens element is positioned closest to the imaged object, the back focal length of the imaging optical lens assembly is BFL2 when the first lens element is positioned closest to the image plane, and they satisfy the relation: $|BFL1-BFL2|<0.1$ mm.

Preferably, BFL1 and BFL2 satisfy the relation: $|BFL1-BFL2|=0$.

When the above relation is satisfied, the image plane can be fixed and the number of moving elements can be reduced, thereby reducing the cost and the variability in the manufacturing of the lens assembly.

In the aforementioned imaging optical lens assembly, it is preferable that the first lens element has a convex object-side surface so that the refractive power thereof can be enhanced to shorten the total track length of the imaging optical lens assembly.

In the aforementioned imaging optical lens assembly, it is preferable that the fourth lens element has a concave image-side surface.

In the aforementioned imaging optical lens assembly, it is preferable that the second lens element has a concave image-side surface and the third lens element has a concave object-side surface and a convex image-side surface, so that accumulation of aberrations can be avoided.

In the present imaging optical lens assembly, the first lens element provides a positive refractive power, and the aperture stop is located near the object side of the imaging optical lens assembly, thereby the exit pupil of the imaging optical lens assembly can be positioned far away from the image plane. Therefore, the light will be projected onto the electronic sensor at a nearly perpendicular angle, and this is the telecentric feature of the image side. The telecentric feature is very important to the photosensitive power of the current solid-state electronic sensor as it can improve the photosensitivity of the electronic sensor to reduce the probability of the occurrence of shading.

In addition, in optical systems with a wide field of view, the correction of distortion and chromatic aberration of magnification is especially necessary, and the correction can be made by placing the aperture stop in a location where the refractive power of the optical system is balanced. In the present imaging optical lens assembly, if the aperture stop is disposed between the first lens element and the imaged object, the telecentric feature will be enhanced to reduce the total track length of the optical system; if the aperture stop is disposed between the first lens element and the second lens element, the wide field of view is emphasized. Such an arrangement of the aperture stop also effectively reduces the sensitivity of the optical system.

In the present imaging optical lens assembly, the lens elements can be made of glass or plastic material. If the lens elements are made of glass, there is more flexibility in distributing the refractive power of the optical system. If plastic material is adopted to produce lens elements, the production cost will be reduced effectively. Additionally, the surfaces of the lens elements can be formed to be aspheric and made to be non-spherical easily, allowing more design parameter freedom which can be used to reduce aberrations and the number of the lens elements, so that the total track length of the imaging optical lens assembly can be shortened effectively.

In the aforementioned imaging optical lens assembly, it is preferable that the third lens element has a positive refractive power so that the refractive power of the optical system can be distributed effectively.

In the aforementioned imaging optical lens assembly, it is preferable that the Abbe number of the second lens element is V2, and it satisfies the relation: $V2<29$.

The above relation facilitates the correction of the chromatic aberration of the optical system.

And it will be more preferable that V2 satisfies the relation: V2<25.

In the aforementioned imaging optical lens assembly, it is preferable that the Abbe number of the first lens element is V1, and it satisfies the relation: 50<V1<62.

The above relation facilitates the correction of the astigmatism of the optical system.

In the aforementioned imaging optical lens assembly, it is preferable that the second lens element has a concave object-side surface.

According to another aspect of the present invention, the aforementioned imaging optical lens assembly further comprises an electronic sensor on which an object is imaged. When the first lens element is positioned closest to the imaged object, the total track length of the imaging optical lens assembly is TTL, which is defined as the on-axis spacing between the object-side surface of the first lens element and the image plane when the first lens element is positioned closest to the imaged object, and the maximum image height of the imaging optical lens assembly is ImgH, which is defined as half of the diagonal length of the effective pixel area of the electronic sensor, and they satisfy the relation: TTL/ImgH<1.95.

The above relation enables the imaging optical lens assembly to maintain a compact form.

Preferred embodiments of the present invention along with the appended drawings will be described in the following paragraphs.

FIG. **1** shows an imaging optical lens assembly in accordance with a first embodiment of the present invention, and FIG. **2** shows the aberration curves of the first embodiment of the present invention. The imaging optical lens assembly of the first embodiment of the present invention, which mainly comprises two lens groups, includes, in order from the object side to the image side:

a first lens group comprising a plastic first lens element **100** with positive refractive power having a convex object-side surface **101** and a convex image-side surface **102**, the object-side and image-side surfaces **101** and **102** of the first lens element **100** being aspheric, no lens element with refractive power being disposed between the first lens element **100** and an imaged object, the first lens element being the only lens element with refractive power in the first lens group

a second lens group comprising, in order from the object side to the image side:

- a plastic second lens element **110** with negative refractive power having a convex object-side surface **111** and a concave image-side surface **112**, the object-side and image-side surfaces **111** and **112** of the second lens element **110** being aspheric;
- a plastic third lens element **120** having a concave object-side surface **121** and a convex image-side surface **122**, the object-side and image-side surfaces **121** and **122** of the third lens element **120** being aspheric; and
- a plastic fourth lens element **130** having a convex object-side surface **131** and a concave image-side surface **132**, the object-side and image-side surfaces **131** and **132** of the fourth lens element **130** being aspheric;

an aperture stop **140** disposed between the first lens element **100** and the imaged object;

an IR filter **150** disposed between the image-side surface **132** of the fourth lens element **130** and the image plane **170**, the IR filter **150** having no influence on the focal length of the imaging optical lens assembly;

a sensor cover glass **160** disposed between the IR filter **150** and the image plane **170**, the sensor cover glass **160** having no influence on the focal length of the imaging optical lens assembly; and

an image plane **170** disposed behind the sensor cover glass **160**.

Focusing is performed by moving the first lens element along the optical axis, such that as a distance between the imaged object and the imaging optical lens assembly changes from far to near, a distance between the first lens element and the imaging surface changes from near to far, and during focusing the other lens elements in the imaging optical lens assembly do not move relative to the imaging plane.

The equation of the aspheric surface profiles is expressed as follows:

$$X(Y)=(Y^2/R)/(1+sqrt(1-(1+k)*(Y/R)^2))+\sum_i (Ai)*(Y^i)$$

wherein:

X: the height of a point on the aspheric surface at a distance Y from the optical axis relative to the tangential plane at the aspheric surface vertex;

Y: the distance from the point on the curve of the aspheric surface to the optical axis;

k: the conic coefficient;

Ai: the aspheric coefficient of order i.

In the first embodiment of the present imaging optical lens assembly, the maximum focal length of the imaging optical lens assembly is f_{max}, the minimum focal length of the imaging optical lens assembly is f_{min}, and they satisfy the relation: $f_{max}/f_{min}=1.02$.

In the first embodiment of the present imaging optical lens assembly, the back focal length of the imaging optical lens assembly is BFL1 when the first lens element **100** is positioned closest to the imaged object, the back focal length of the imaging optical lens assembly is BFL2 when the first lens element **100** is positioned closest to the image plane **170**, and they satisfy the relation: |BFL1−BFL2|=0.0.

In the first embodiment of the present imaging optical lens assembly, the on-axis spacing between the image-side surface **102** of the first lens element **100** and the image plane **170** is D1 when the first lens element **100** is positioned closest to the imaged object, the on-axis spacing between the image-side surface **102** of the first lens element **100** and the image plane **170** is D2 when the first lens element **100** is positioned closest to the image plane **170**, the focal length of the imaging optical lens assembly is f when the first lens element **100** is positioned closest to the image plane **170**, and they satisfy the relation: (D1−D2)*100/f=2.02.

In the first embodiment of the present imaging optical lens assembly, the Abbe number of the first lens element **100** is V1, and it satisfies the relation: V1=55.9.

In the first embodiment of the present imaging optical lens assembly, the Abbe number of the second lens element **110** is V2, and it satisfies the relation: V2=23.4.

In the first embodiment of the present imaging optical lens assembly, the on-axis spacing between the third lens element **120** and the fourth lens element **130** is T34, the on-axis spacing between the second lens element **110** and the third lens element **120** is T23, and they satisfy the relation: T34/T23=0.11.

In the first embodiment of the present imaging optical lens assembly, the focal length of the imaging optical lens assem-

bly is f when the first lens element **100** is positioned closest to the image plane **170**, the focal length of the first lens element **100** is f1, the focal length of the third lens element **120** is f3, and they satisfy the relations: f/f1=1.43, f/f3=1.42.

In the first embodiment of the present imaging optical lens assembly, the image plane **170** is provided with an electronic sensor on which an object is imaged. When the first lens element **100** is positioned closest to the imaged object, the total track length of the imaging optical lens assembly is TTL and the maximum image height of the imaging optical lens assembly is ImgH, and they satisfy the relation: TTL/ImgH=1.84.

The detailed optical data of the first embodiment is shown in FIG. **7** (TABLE 1), and the aspheric surface data is shown in FIG. **8** (TABLE 2), wherein the units of the radius of curvature, the thickness and the focal length are expressed in mm, and HFOV is half of the maximal field of view.

FIG. **3** shows an imaging optical lens assembly in accordance with a second embodiment of the present invention, and FIG. **4** shows the aberration curves of the second embodiment of the present invention. The imaging optical lens assembly of the second embodiment of the present invention, which mainly comprises two lens groups, includes, in order from the object side to the image side:

a first lens group comprising a plastic first lens element **300** with positive refractive power having a convex object-side surface **301** and a convex image-side surface **302**, the object-side and image-side surfaces **301** and **302** of the first lens element **300** being aspheric, no lens element with refractive power being disposed between the first lens element **300** and an imaged object, the first lens element being the only lens element with refractive power in the first lens group;

a second lens group comprising, in order from the object side to the image side:

- a plastic second lens element **310** with negative refractive power having a concave object-side surface **311** and a concave image-side surface **312**, the object-side and image-side surfaces **311** and **312** of the second lens element **310** being aspheric;
- a plastic third lens element **320** having a concave object-side surface **321** and a convex image-side surface **322**, the object-side and image-side surfaces **321** and **322** of the third lens element **320** being aspheric; and
- a plastic fourth lens element **330** having a convex object-side surface **331** and a concave image-side surface **332**, the object-side and image-side surfaces **331** and **332** of the fourth lens element **330** being aspheric;

an aperture stop **340** disposed between the first lens element **300** and the imaged object;

an IR filter **350** disposed between the image-side surface **332** of the fourth lens element **330** and the image plane **370**, the IR filter **350** having no influence on the focal length of the imaging optical lens assembly;

a sensor cover glass **360** disposed between the IR filter **350** and the image plane **370**, the sensor cover glass **360** having no influence on the focal length of the imaging optical lens assembly; and

an image plane **370** disposed behind the sensor cover glass **360**.

Focusing is performed by moving the first lens element along the optical axis, such that as a distance between the imaged object and the imaging optical lens assembly changes from far to near, a distance between the first lens element and the imaging surface changes from near to far, and during focusing the other lens elements in the imaging optical lens assembly do not move relative to the imaging plane.

The equation of the aspheric surface profiles of the second embodiment has the same form as that of the first embodiment.

In the second embodiment of the present imaging optical lens assembly, the maximum focal length of the imaging optical lens assembly is f_{max}, the minimum focal length of the imaging optical lens assembly is f_{min}, and they satisfy the relation: f_{max}/f_{min}=1.03.

In the second embodiment of the present imaging optical lens assembly, the back focal length of the imaging optical lens assembly is BFL1 when the first lens element **300** is positioned closest to the imaged object, the back focal length of the imaging optical lens assembly is BFL2 when the first lens element **300** is positioned closest to the image plane **370**, and they satisfy the relation: |BFL1−BFL2|=0.0.

In the second embodiment of the present imaging optical lens assembly, the on-axis spacing between the image-side surface **302** of the first lens element **300** and the image plane **370** is D1 when the first lens element **300** is positioned closest to the imaged object, the on-axis spacing between the image-side surface **302** of the first lens element **300** and the image plane **370** is D2 when the first lens element **300** is positioned closest to the image plane **370**, the focal length of the imaging optical lens assembly is f when the first lens element **300** is positioned closest to the image plane **370**, and they satisfy the relation: (D1−D2)*100/f=1.98.

In the second embodiment of the present imaging optical lens assembly, the Abbe number of the first lens element **300** is V1, and it satisfies the relation: V1=55.9.

In the second embodiment of the present imaging optical lens assembly, the Abbe number of the second lens element **310** is V2, and it satisfies the relation: V2=23.4.

In the second embodiment of the present imaging optical lens assembly, the on-axis spacing between the third lens element **320** and the fourth lens element **330** is T34, the on-axis spacing between the second lens element **310** and the third lens element **320** is T23, and they satisfy the relation: T34/T23=1.19.

In the second embodiment of the present imaging optical lens assembly, the focal length of the imaging optical lens assembly is f when the first lens element **300** is positioned closest to the image plane **370**, the focal length of the first lens element **300** is f1, the focal length of the third lens element **320** is f3, and they satisfy the relations: f/f1=1.42, f/f3=0.90.

In the second embodiment of the present imaging optical lens assembly, the image plane **370** is provided with an electronic sensor on which an object is imaged. When the first lens element **300** is positioned closest to the imaged object, the total track length of the imaging optical lens assembly is TTL and the maximum image height of the imaging optical lens assembly is ImgH, and they satisfy the relation: TTL/ImgH=1.75.

The detailed optical data of the second embodiment is shown in FIG. **9** (TABLE 3), and the aspheric surface data is shown in FIG. **10** (TABLE 4), wherein the units of the radius of curvature, the thickness and the focal length are expressed in mm, and HFOV is half of the maximal field of view.

FIG. **5** shows an imaging optical lens assembly in accordance with a third embodiment of the present invention, and FIG. **6** shows the aberration curves of the third embodiment of the present invention. The imaging optical lens assembly of the third embodiment of the present invention, which mainly comprises two lens groups, includes, in order from the object side to the image side:

a first lens group comprising a plastic first lens element **500** with positive refractive power having a convex object-side surface **501** and a convex image-side surface **502**, the object-

side and image-side surfaces **501** and **502** of the first lens element **500** being aspheric, no lens element with refractive power being disposed between the first lens element **500** and an imaged object, the first lens element being the only lens element with refractive power in the first lens group;

a second lens group comprising, in order from the object side to the image side:

a plastic second lens element **510** with negative refractive power having a concave object-side surface **511** and a concave image-side surface **512**, the object-side and image-side surfaces **511** and **512** of the second lens element **510** being aspheric;

a plastic third lens element **520** having a concave object-side surface **521** and a convex image-side surface **522**, the object-side and image-side surfaces **521** and **522** of the third lens element **520** being aspheric; and

a plastic fourth lens element **530** having a convex object-side surface **531** and a concave image-side surface **532**, the object-side and image-side surfaces **531** and **532** of the fourth lens element **530** being aspheric;

an aperture stop **540** disposed between the first lens element **500** and the imaged object;

an IR filter **550** disposed between the image-side surface **532** of the fourth lens element **530** and the image plane **570**, the IR filter **550** having no influence on the focal length of the imaging optical lens assembly;

a sensor cover glass **560** disposed between the IR filter **550** and the image plane **570**, the sensor cover glass **560** having no influence on the focal length of the imaging optical lens assembly; and

an image plane **570** disposed behind the sensor cover glass **560**.

Focusing is performed by moving the first lens element along the optical axis, such that as a distance between the imaged object and the imaging optical lens assembly changes from far to near, a distance between the first lens element and the imaging surface changes from near to far, and during focusing the other lens elements in the imaging optical lens assembly do not move relative to the imaging plane.

The equation of the aspheric surface profiles of the third embodiment has the same form as that of the first embodiment.

In the third embodiment of the present imaging optical lens assembly, the maximum focal length of the imaging optical lens assembly is f_{max}, the minimum focal length of the imaging optical lens assembly is f_{min} and they satisfy the relation: $f_{max}/f_{min}=1.03$.

In the third embodiment of the present imaging optical lens assembly, the back focal length of the imaging optical lens assembly is BFL1 when the first lens element **500** is positioned closest to the imaged object, the back focal length of the imaging optical lens assembly is BFL2 when the first lens element **500** is positioned closest to the image plane **570**, and they satisfy the relation: $|BFL1-BFL2|=0.0$.

In the third embodiment of the present imaging optical lens assembly, the on-axis spacing between the image-side surface **502** of the first lens element **500** and the image plane **570** is D1 when the first lens element **500** is positioned closest to the imaged object, the on-axis spacing between the image-side surface **502** of the first lens element **500** and the image plane **570** is D2 when the first lens element **500** is positioned closest to the image plane **570**, the focal length of the imaging optical lens assembly is f when the first lens element **500** is positioned closest to the image plane **570**, and they satisfy the relation: $(D1-D2)*100/f=1.87$.

In the third embodiment of the present imaging optical lens assembly, the Abbe number of the first lens element **500** is V1, and it satisfies the relation: V1=55.9.

In the third embodiment of the present imaging optical lens assembly, the Abbe number of the second lens element **510** is V2, and it satisfies the relation: V2=23.4.

In the third embodiment of the present imaging optical lens assembly, the on-axis spacing between the third lens element **520** and the fourth lens element **530** is T34, the on-axis spacing between the second lens element **510** and the third lens element **520** is T23, and they satisfy the relation: T34/T23=0.47.

In the third embodiment of the present imaging optical lens assembly, the focal length of the imaging optical lens assembly is f when the first lens element **500** is positioned closest to the image plane **570**, the focal length of the first lens element **500** is f1, the focal length of the third lens element **520** is f3, and they satisfy the relations: f/f1=1.46, f/f3=1.31.

In the third embodiment of the present imaging optical lens assembly, the image plane **570** is provided with an electronic sensor on which an object is imaged. When the first lens element **500** is positioned closest to the imaged object, the total track length of the imaging optical lens assembly is TTL and the maximum image height of the imaging optical lens assembly is ImgH, and they satisfy the relation: TTL/ImgH=1.75.

The detailed optical data of the third embodiment is shown in FIG. **11** (TABLE 5), and the aspheric surface data is shown in FIG. **12** (TABLE 6), wherein the units of the radius of curvature, the thickness and the focal length are expressed in mm, and HFOV is half of the maximal field of view.

It is to be noted that TABLES 1-6 (illustrated in FIGS. **7-12** respectively) show different data of the different embodiments, however, the data of the different embodiments are obtained from experiments. Therefore, any imaging optical lens assembly of the same structure is considered to be within the scope of the present invention even if it uses different data. TABLE 7 (illustrated in FIG. **13**) shows the data of the respective embodiments resulted from the equations.

The aforementioned arrangement of optical elements and focusing adjustment method enable the imaging optical lens assembly to obtain good image quality. In addition, the focusing adjustment method introduced in the present invention requires less power consumption and facilitates a significant reduction in the total track length as compared to a conventional photographing lens with focusing adjustment function.

What is claimed is:

1. An imaging optical lens assembly including, in order from an object side to an image side:

a first lens group comprising a first lens element with positive refractive power, no lens element with refractive power being disposed between the first lens element and an imaged object, the first lens element being the only lens element with refractive power in the first lens group; and

a second lens group comprising, in order from the object side to the image side:

a second lens element with negative refractive power;

a third lens element; and

a fourth lens element;

wherein focusing adjustment is performed by moving the first lens element along an optical axis, such that as a distance between the object and the imaging optical lens assembly changes from far to near, a distance between the first lens element and an image plane changes from near to far, and during focusing the other lens elements in the imaging optical lens assembly do not move relative to the imaging plane; and

wherein the number of the lens elements with refractive power in the imaging optical lens assembly is N, and it satisfies the relation: $4 \leqq N \leqq 5$.

2. The imaging optical lens assembly according to claim **1**, wherein a maximum focal length of the imaging optical lens assembly is f_{max}, a minimum focal length of the imaging optical lens assembly is f_{min}, and they satisfy the relation: $1 \leqq f_{max}/f_{min} \leqq 1.05$.

3. The imaging optical lens assembly according to claim **2**, wherein a back focal length of the imaging optical lens assembly is BFL1 when the first lens element is positioned closest to the imaged object, a back focal length of the imaging optical lens assembly is BFL2 when the first lens element is positioned closest to the image plane, and they satisfy the relation: $|BFL1-BFL2|<0.1$ mm.

4. The imaging optical lens assembly according to claim **3**, wherein an on-axis spacing between the image-side surface of the first lens element and the image plane is D1 when the first lens element is positioned closest to the imaged object, an on-axis spacing between the image-side surface of the first lens element and the image plane is D2 when the first lens element is positioned closest to the image plane, a focal length of the imaging optical lens element is f when the first lens element is positioned closest to the image plane, and they satisfy the relation: $1.0<(D1-D2)*100/f<3.0$.

5. The imaging optical lens assembly according to claim **3**, wherein the first lens element has a convex object-side surface.

6. The imaging optical lens assembly according to claim **5**, wherein the fourth lens element has a concave image-side surface.

7. The imaging optical lens assembly according to claim **6**, wherein the second lens element has a concave image-side surface and the third lens element has a concave object-side surface and a convex image-side surface.

8. The imaging optical lens assembly according to claim **7**, wherein the object-side and image-side surfaces of at least three of said lens elements are aspheric, and an aperture stop is disposed between the first lens element and the imaged object.

9. The imaging optical lens assembly according to claim **8**, wherein the third lens element has a positive refractive power.

10. The imaging optical lens assembly according to claim **9**, wherein the second, third and fourth lens elements are made of plastic material; and wherein an Abbe number of the second lens element is V2, and it satisfies the relation: $V2<29$.

11. The imaging optical lens assembly according to claim **10**, wherein the first lens element is made of plastic material; and wherein an Abbe number of the first lens element is V1, and it satisfies the relation: $50<V1<62$.

12. The imaging optical lens assembly according to claim **9**, wherein the second lens element has a concave object-side surface.

13. The imaging optical lens assembly according to claim **12**, wherein an on-axis spacing between the third lens element and the fourth lens element is T34, an on-axis spacing between the second lens element and the third lens element is T23, and they satisfy the relation: $0.2<T34/T23<1.6$.

14. The imaging optical lens assembly according to claim **4**, wherein a focal length of the first lens element is f1, a focal length of the third lens element is f3, and they satisfy the relations: $1.0<f/f1<1.7$, $0.6<f/f3<1.8$.

15. The imaging optical lens assembly according to claim **14** further comprising an electronic sensor on which an object is imaged; wherein when the first lens element is positioned closest to the imaged object, a total track length of the imaging optical lens assembly is TTL and a maximum image height of the imaging optical lens assembly is ImgH, and they satisfy the relation: $TTL/ImgH<1.95$.

16. The imaging optical lens assembly according to claim **1** further comprising an electronic sensor on which an object is imaged; wherein when the first lens element is positioned closest to the imaged object, the total track length of the imaging optical lens assembly is TTL and the maximum image height of the imaging optical lens assembly is ImgH, and they satisfy the relation: $TTL/ImgH<1.95$.

17. The imaging optical lens assembly according to claim **11**, wherein the Abbe number of the second lens element is V2, and it satisfies the relation: $V2<25$.

18. A method for performing focusing for an imaging optical lens assembly, wherein the imaging optical lens assembly includes, in order from an object side to an image side: a first lens group comprising a first lens element with positive refractive power, no lens element with refractive power being disposed between the first lens element and an imaged object, the first lens element being the only lens element with refractive power in the first lens group; and a second lens group comprising, in order from the object side to the image side: a second lens element with negative refractive power; a third lens element and a fourth lens element; and wherein the method for performing focusing includes moving the first lens element along an optical axis, such that as a distance between the imaged object and the imaging optical lens assembly changes from far to near, a distance between the first lens element and an image plane changes from near to far.

19. The method for performing focusing for an imaging optical lens assembly according to claim **18**, wherein the object is imaged on an electronic sensor.

* * * * *

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Iwasaki et al.

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(45) **Date of Patent: Jun. 13, 2017**

(54) **IMAGING LENS AND IMAGING APPARATUS EQUIPPED WITH THE IMAGING LENS**

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(73) Assignee: **FUJIFILM Corporation**, Tokyo (JP)

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(21) Appl. No.: **14/857,756**

(22) Filed: **Sep. 17, 2015**

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Related U.S. Application Data

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(30) **Foreign Application Priority Data**

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G02B 9/64 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G02B 13/0045*** (2013.01); ***G02B 5/005*** (2013.01); ***G02B 9/34*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC .. G02B 13/0045; G02B 9/60; G02B 27/0025; G02B 13/18; G02B 5/005; G02B 13/002; G02B 13/004; G02B 9/34
(Continued)

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(57) **ABSTRACT**

An imaging lens is constituted essentially by four or more lenses, including, in order from the object side to the image side: a first lens having a positive refractive power; a second lens having a negative refractive power; and a plurality of other lenses. The conditional formulae below are satisfied.

$$0.8<TL/f<1.0 \quad (1)$$

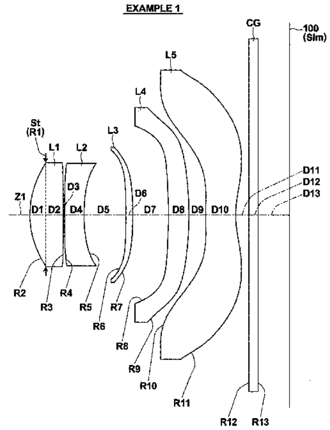
$$1.0<f/fl<3.0 \quad (2)$$

$$2.03\text{ mm}<f<5.16\text{ mm} \quad (3)$$

$$1.0\text{ mm}<fl<3.0\text{ mm} \quad (4)$$

wherein f is the focal length of the entire lens system, fl is the focal length of the first lens, TL is the distance along the optical axis from the surface of the first lens toward the object side to the paraxial focal point
(Continued)

EXAMPLE 1



position at the image side in the case that the portion corresponding to back focus is an air converted length.

17 Claims, 10 Drawing Sheets

(51) **Int. Cl.**

G02B 13/00	(2006.01)
G02B 9/34	(2006.01)
G02B 9/60	(2006.01)
G02B 9/62	(2006.01)
G02B 5/00	(2006.01)
G02B 27/00	(2006.01)

(52) **U.S. Cl.**
CPC ***G02B 9/60*** (2013.01); ***G02B 9/62*** (2013.01); ***G02B 13/004*** (2013.01); ***G02B 27/0025*** (2013.01); *G02B 13/002* (2013.01); *G02B 13/18* (2013.01)

(58) **Field of Classification Search**
USPC 359/714, 715, 739, 740, 763, 764, 773
See application file for complete search history.

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FIG.1

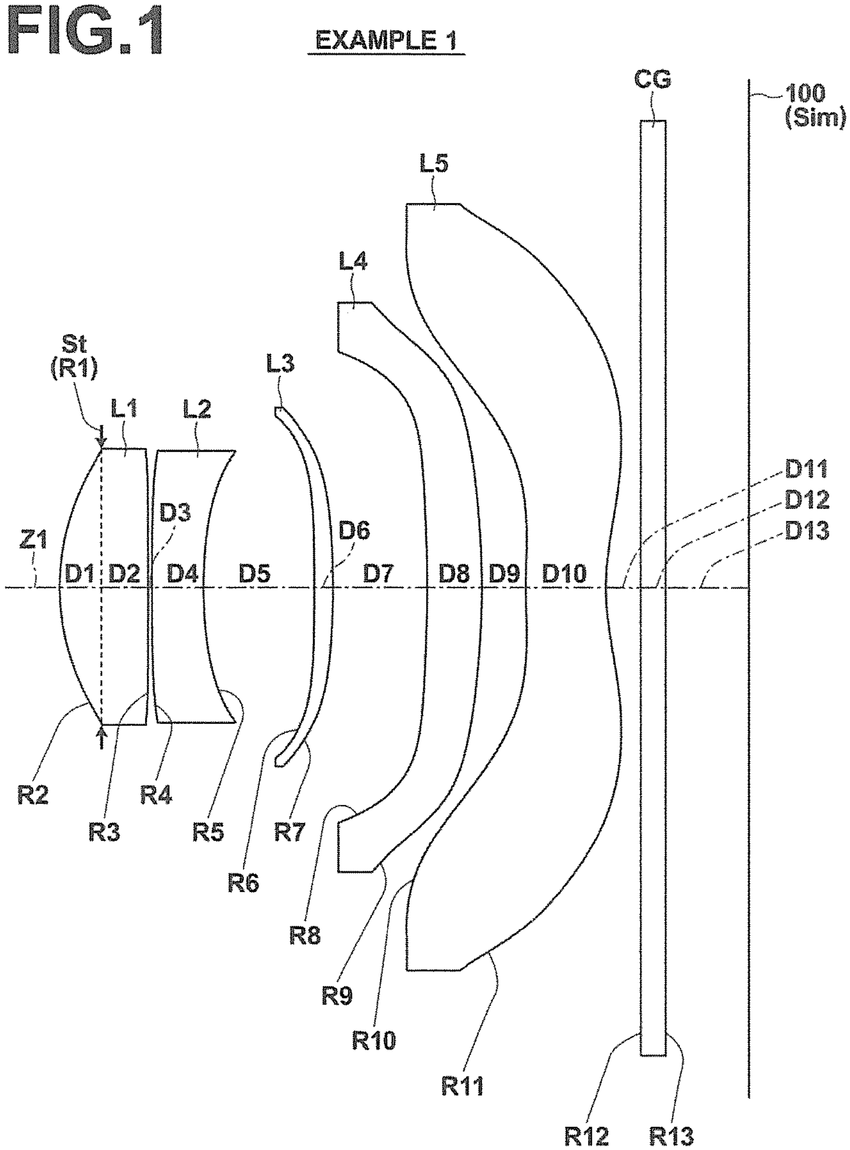

EXAMPLE 1
CG
100
(Sim)
L5
L4
L3
St
(R1)
L1
L2
D11
D12
D13
D3
D6
Z1
D1
D2
D4
D5
D7
D8
D9
D10
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13

FIG.2

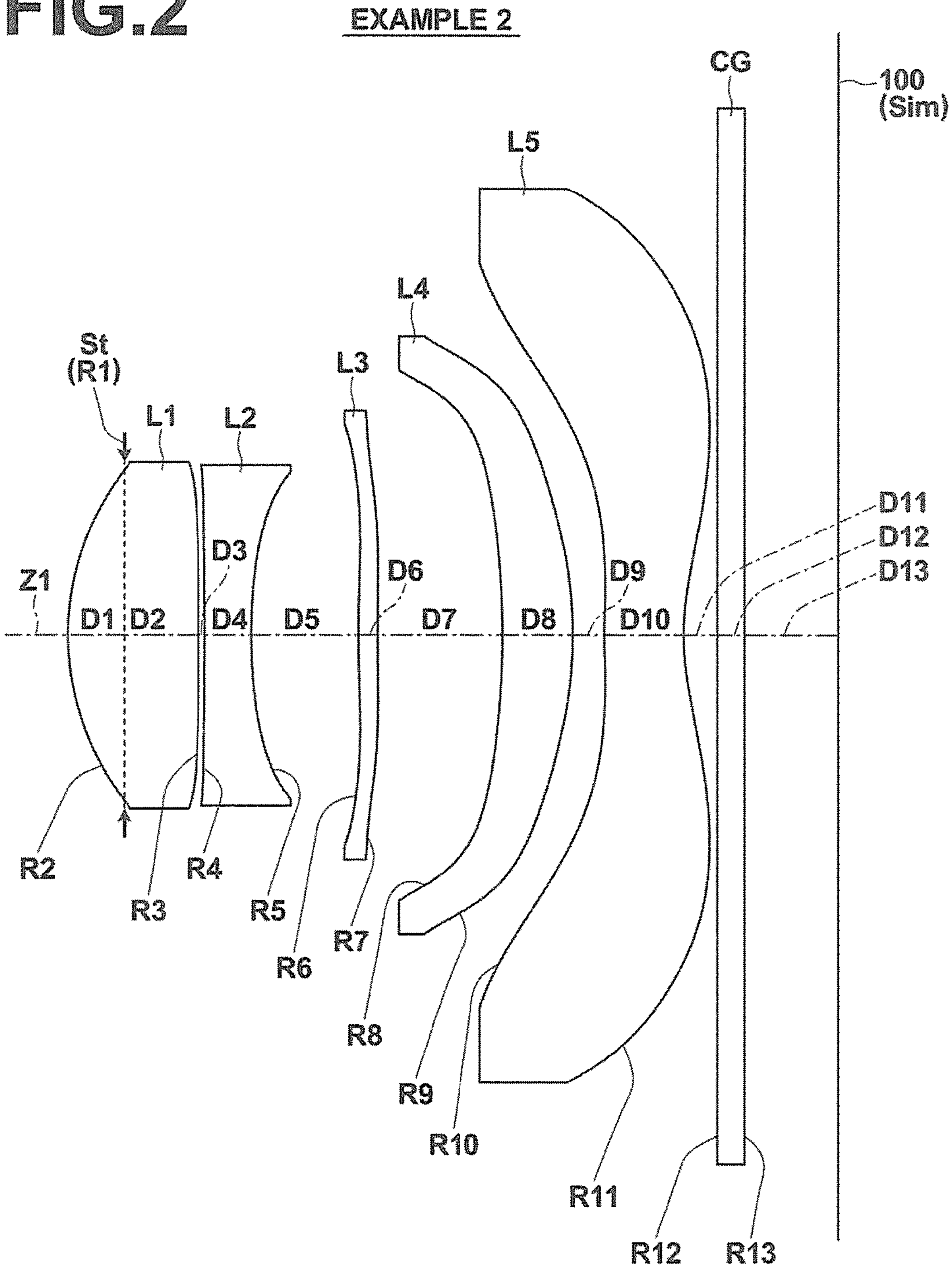

EXAMPLE 2
CG
100 (Sim)
L5
L4
St (R1)
L3
L1
L2
D11
D12
D13
D3
D6
D9
Z1
D1
D2
D4
D5
D7
D8
D10
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13

FIG.3

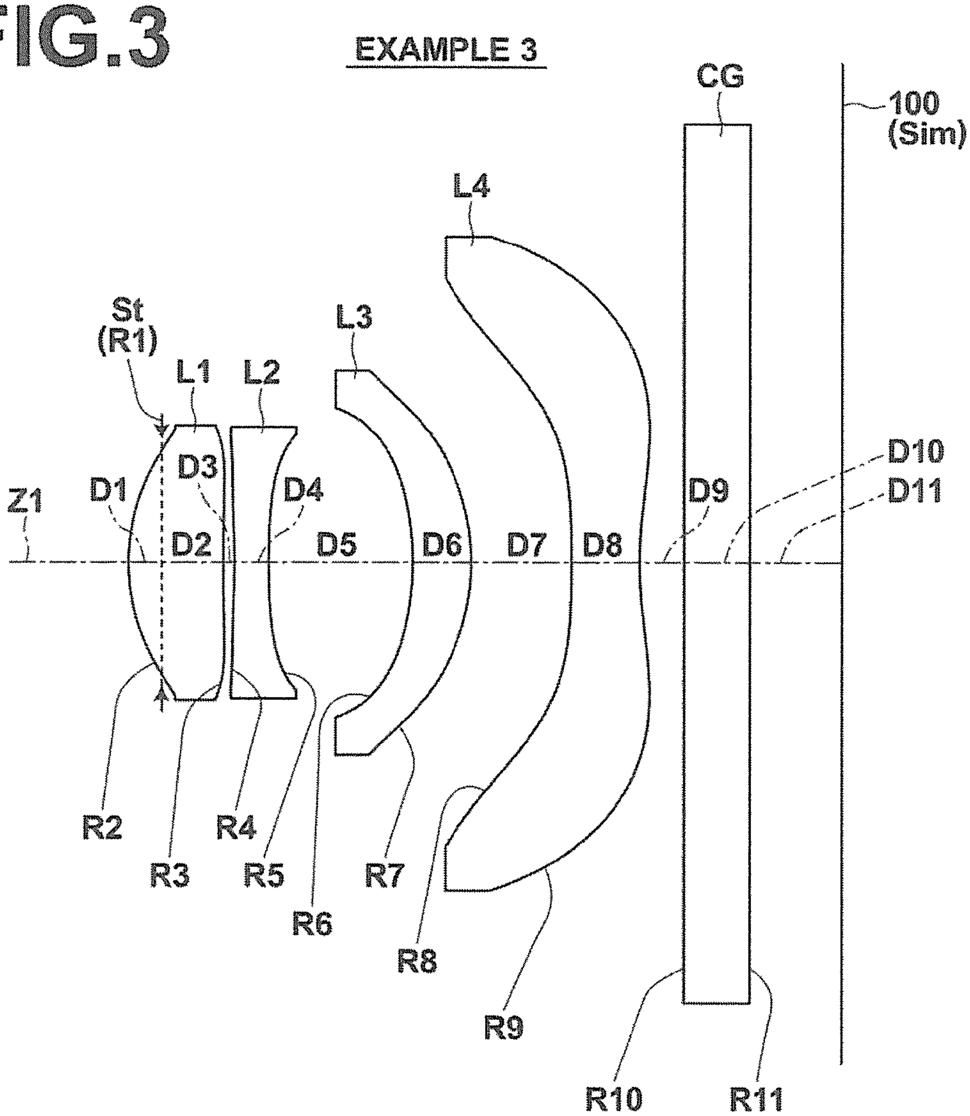

EXAMPLE 3
CG
100
(Sim)
L4
L3
St
(R1)
L1
L2
D10
D11
Z1
D1
D3
D4
D9
D2
D5
D6
D7
D8
R2
R4
R3
R5
R7
R6
R8
R9
R10
R11

FIG.4

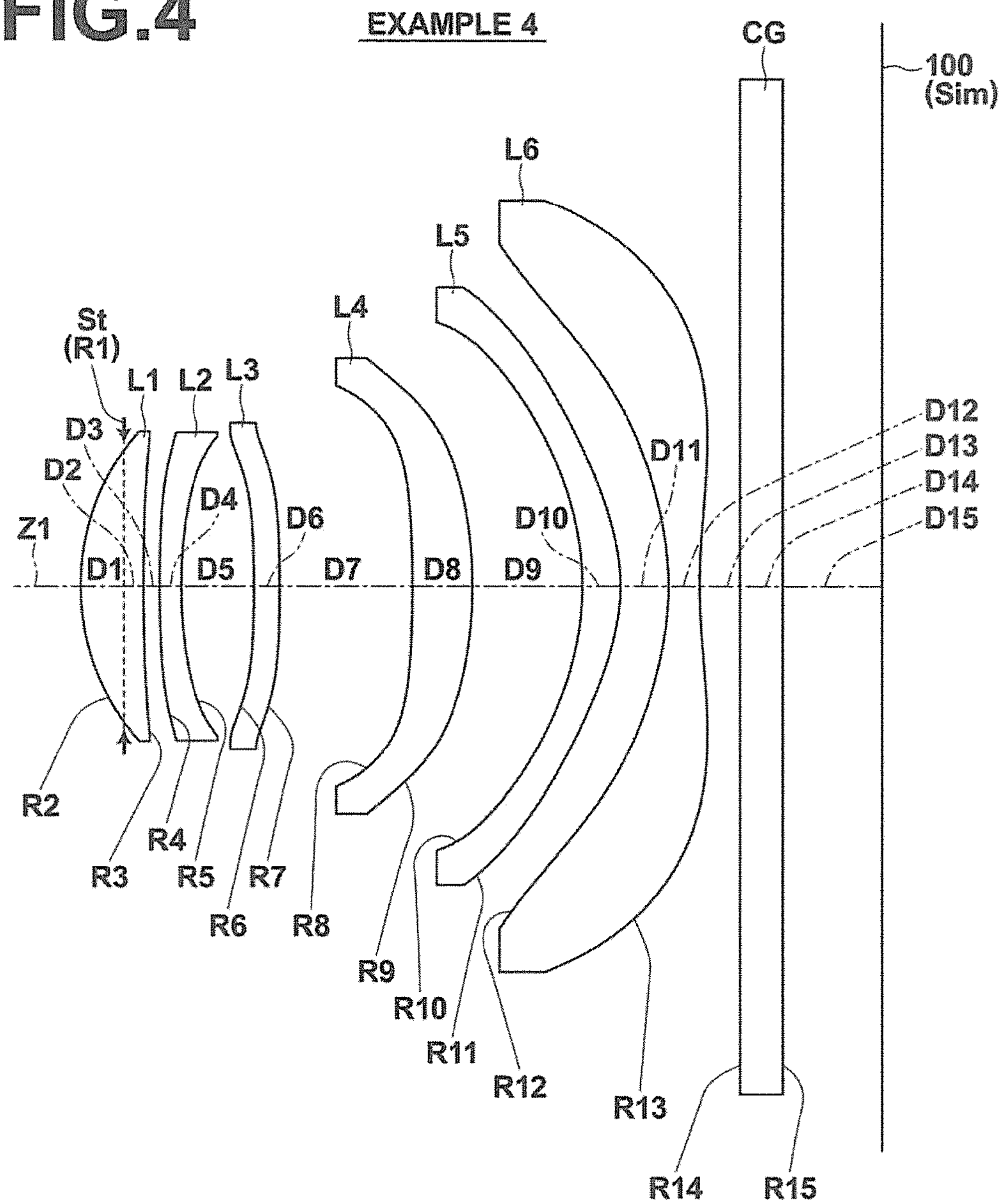

EXAMPLE 4
CG
100
(Sim)
L6
L5
L4
St
(R1)
L1
L2
L3
D3
D2
D4
D6
Z1
D1
D5
D7
D8
D9
D10
D11
D12
D13
D14
D15
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15

FIG.5

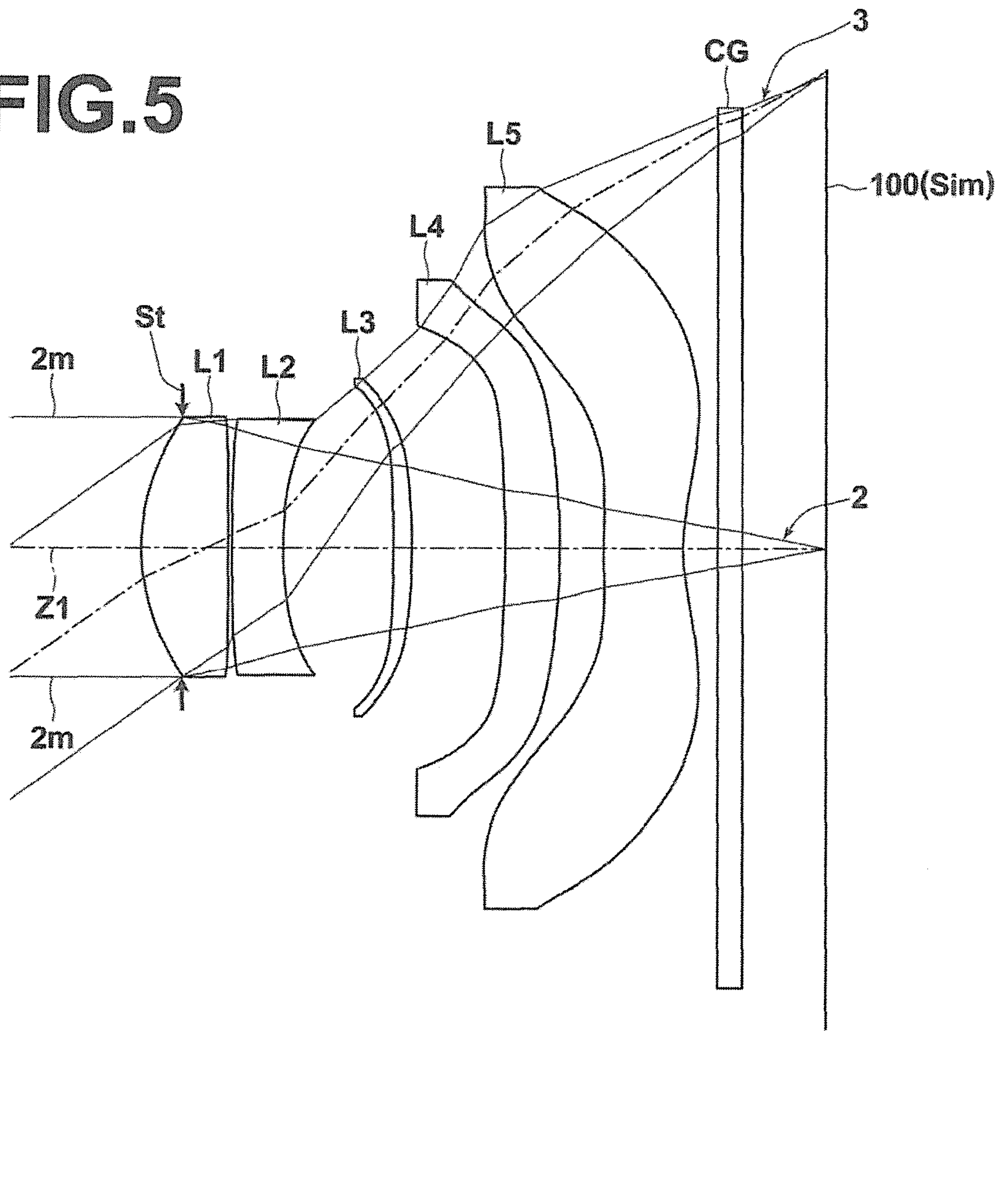


FIG.6

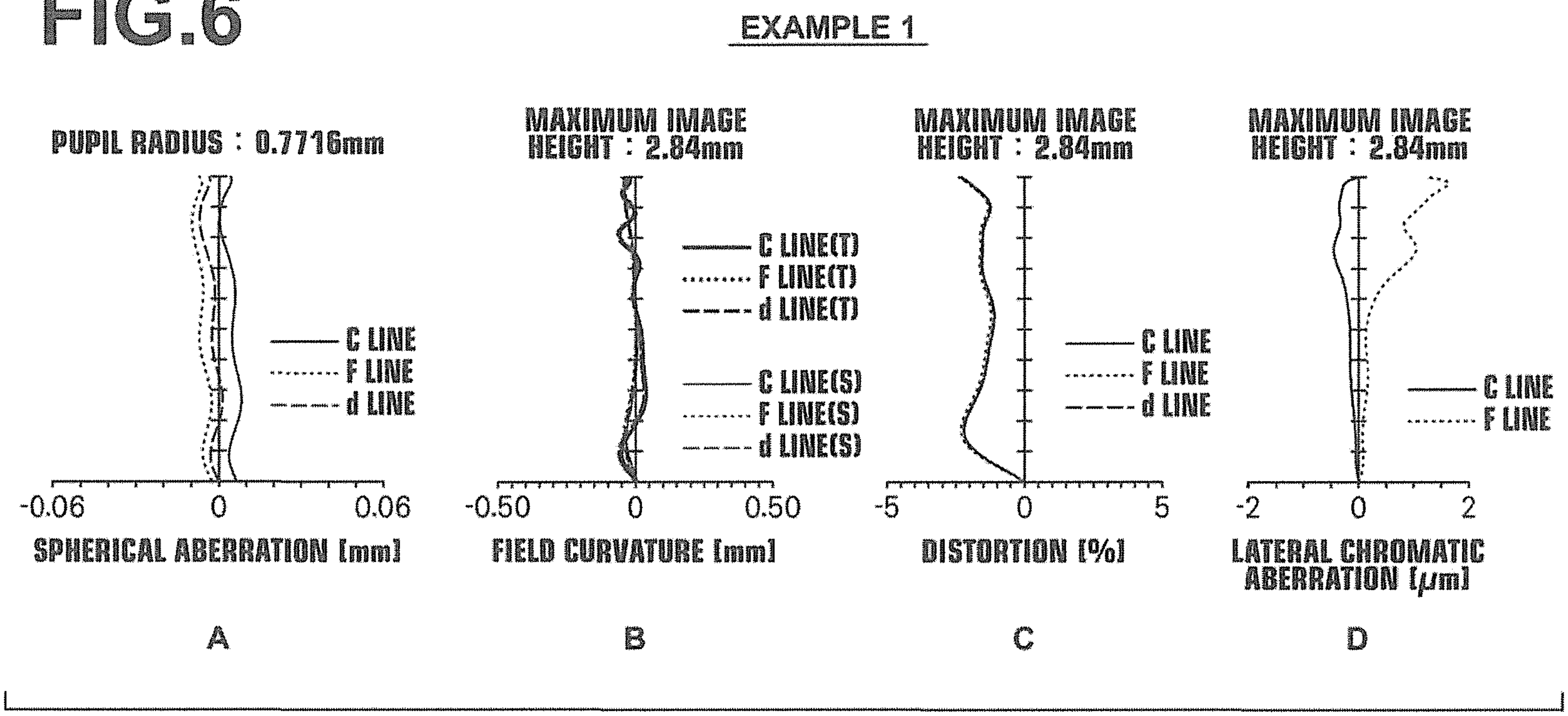

EXAMPLE 1
PUPIL RADIUS : 0.7716mm
C LINE
F LINE
d LINE
-0.06
0
0.06
SPHERICAL ABERRATION [mm]
A
MAXIMUM IMAGE HEIGHT : 2.84mm
C LINE(T)
F LINE(T)
d LINE(T)
C LINE(S)
F LINE(S)
d LINE(S)
-0.50
0
0.50
FIELD CURVATURE [mm]
B
MAXIMUM IMAGE HEIGHT : 2.84mm
C LINE
F LINE
d LINE
-5
0
5
DISTORTION [%]
C
MAXIMUM IMAGE HEIGHT : 2.84mm
C LINE
F LINE
-2
0
2
LATERAL CHROMATIC ABERRATION [μm]
D

FIG.7

EXAMPLE 2

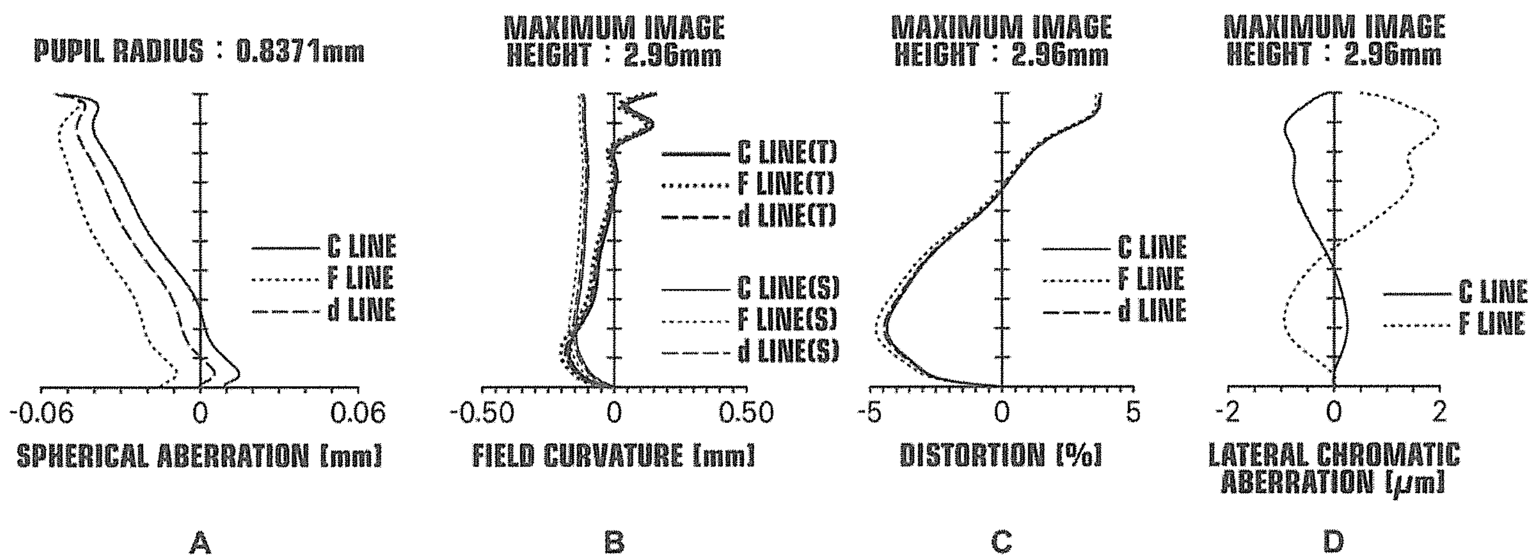
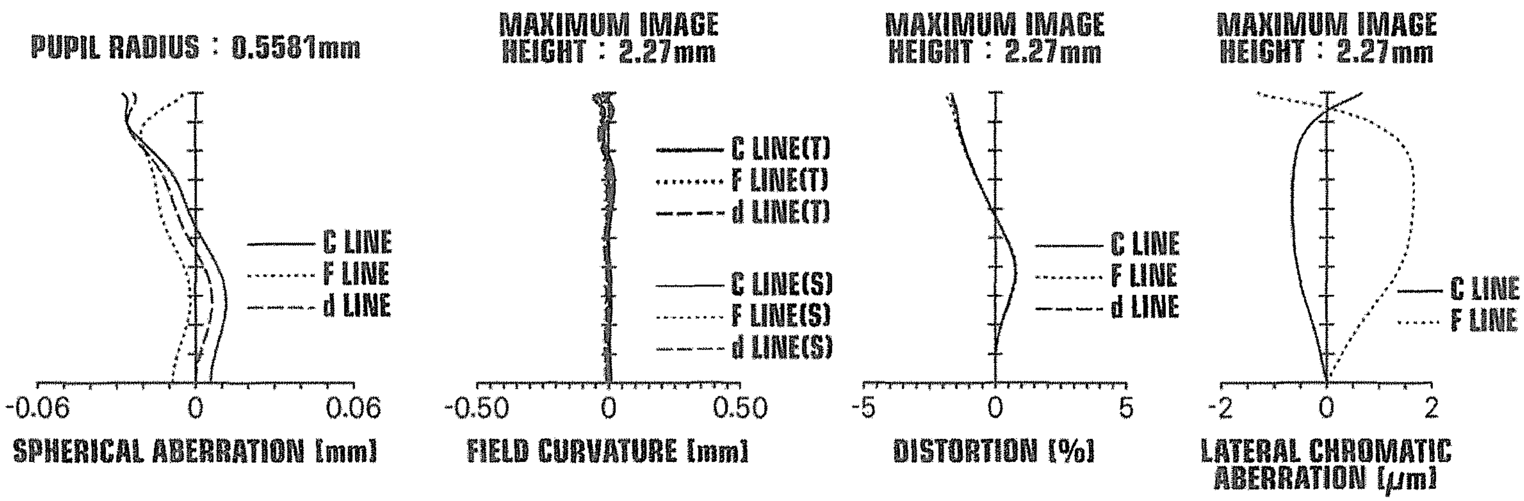


FIG.8

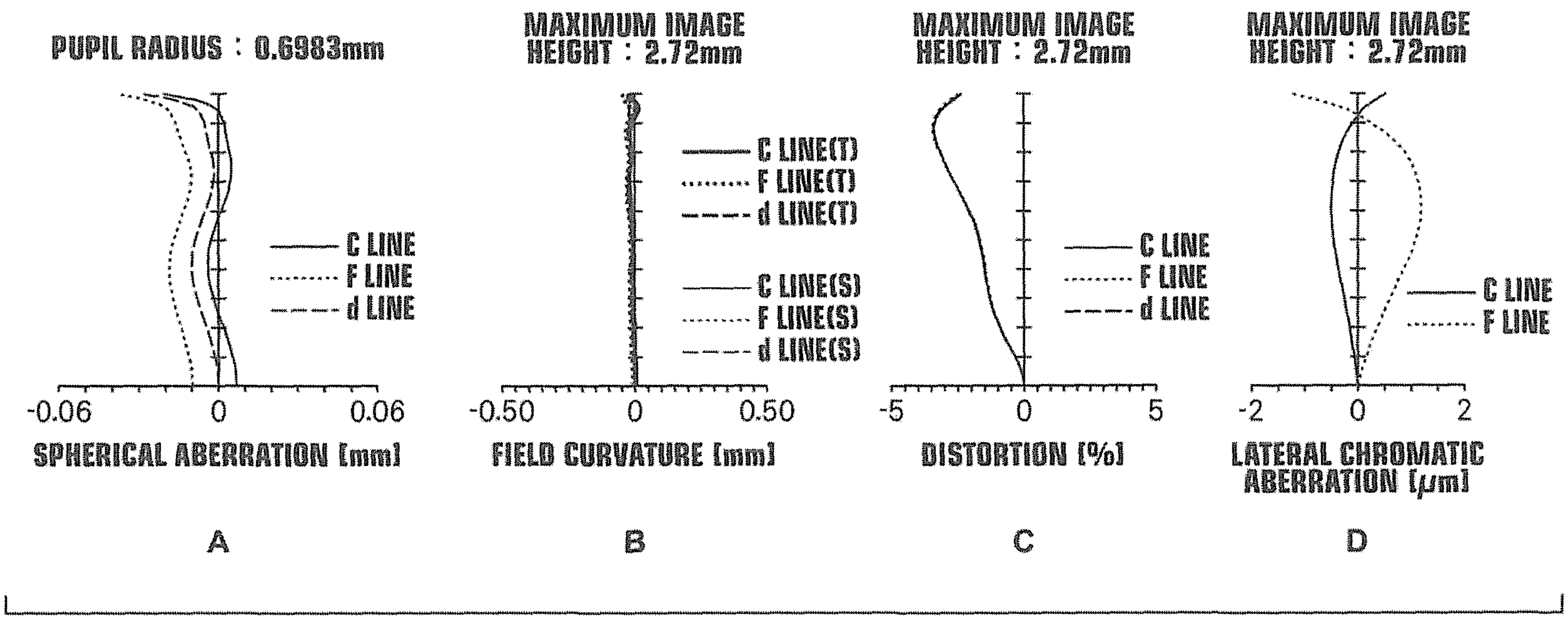
EXAMPLE 3



A B C D

FIG.9

EXAMPLE 4



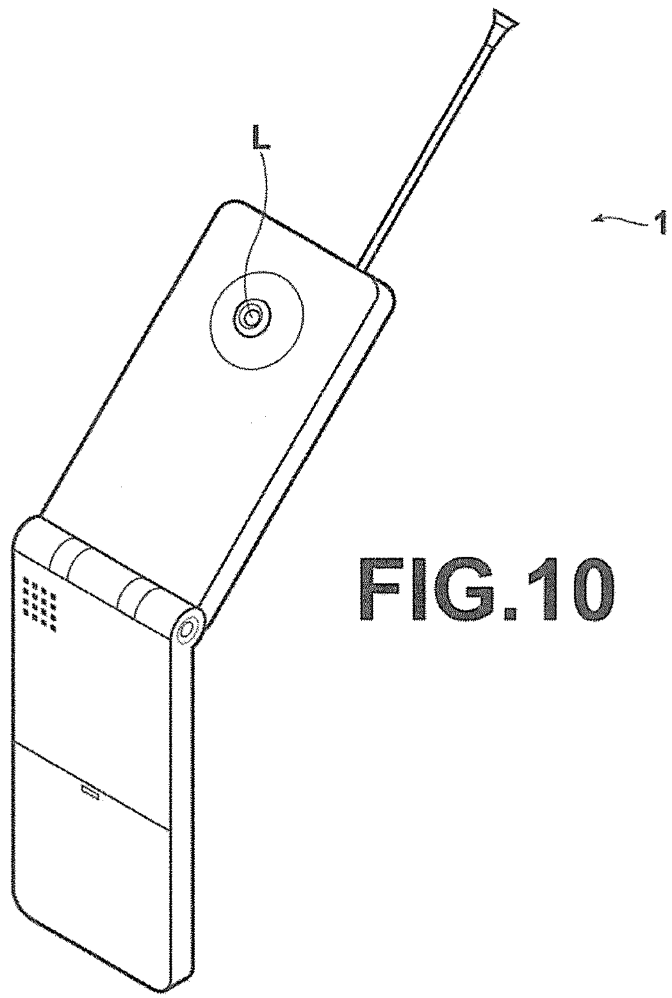
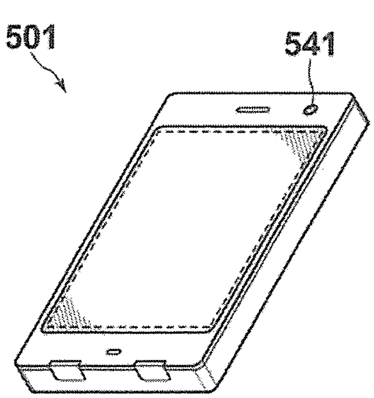


FIG.10

FIG.11



IMAGING LENS AND IMAGING APPARATUS EQUIPPED WITH THE IMAGING LENS

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a Continuation of PCT International Application No. PCT/JP2013/007642 filed on Dec. 26, 2013, which claims priority under 35 U.S.C. §119(a) to Japanese Patent Application No. 2013-061647 filed on Mar. 25, 2013. Each of the above applications is hereby expressly incorporated by reference, in its entirety, into the present application.

BACKGROUND

The present disclosure is related to a fixed focus imaging lens for forming optical images of subjects onto an imaging element such as a CCD (Charge Coupled Device) and a CMOS (Complementary Metal Oxide Semiconductor). The present disclosure is also related to an imaging apparatus provided with the imaging lens that performs photography such as a digital still camera, a cellular telephone with a built in camera, a PDA (Personal Digital Assistant), a smart phone, a tablet type terminal, and a portable gaming device.

Accompanying the recent spread of personal computers in households, digital still cameras capable of inputting image data such as photographed scenes and portraits into personal computers are rapidly becoming available. In addition, many cellular telephones, smart phones, and tablet type terminals are being equipped with camera modules for inputting images. Imaging elements such as CCD's and CMOS's are employed in these devices having photography functions. Recently, miniaturization of these imaging elements is advancing, and there is demand for miniaturization of the entirety of the photography devices as well as imaging lenses to be mounted thereon. At the same time, the number of pixels in imaging elements is increasing, and there is demand for high resolution and high performance of imaging lenses accompanying this increase.

Imaging lenses in the above technical field have been proposed in U.S. Pat. No. 7,274,515 and Korean Patent Publication No. 2010-0062480, for example. U.S. Pat. No. 7,274,515 discloses an imaging lens having a four or five lens configuration as a two focal point optical system for cellular telephones. Korean Patent Publication No. 2010-0062480 discloses an imaging lens having a five lens configuration, which takes imaging elements having high resolution into consideration.

SUMMARY

Recently, miniaturization of imaging elements is also progressing, and there is demand for miniaturization of imaging apparatuses as a whole as well as imaging lenses to be mounted therein. Particularly, demand for shortening of the total lengths of lenses is increasing for imaging lenses which are employed in devices such as smart phones and tablet terminals, which are becoming progressively thinner. In addition, angles of view of photography are an important item in the above devices. Therefore, there is demand for high resolution and a shortening of the total lengths of lenses, while maintaining an angle of view which is standard for portable terminals.

It is necessary for the imaging lens disclosed in U.S. Pat. No. 7,274,515 to further shorten the total length thereof, in order to satisfy all of the above demands. In addition, it is necessary for the imaging lens disclosed in Korean Patent Publication No. 2010-0062480 above to widen the angle of view and to further shorten the total length thereof.

The present disclosure has been developed in view of the foregoing points. The present disclosure provides an imaging lens that can realize a shortening of the total length and high imaging performance which is compatible with an increased number of pixels, while maintaining an angle of view which is standard for portable terminals. The present disclosure also provides an imaging apparatus equipped with this imaging lens, which is capable of obtaining high resolution photographed images.

An imaging lens of the present disclosure consists of four or more lenses, including, in order from the object side to the image side:

a first lens having a positive refractive power;

a second lens having a negative refractive power; and

a plurality of other lenses;

in which the conditional formulae below are satisfied.

$$0.8<TL/f<1.0 \quad (1)$$

$$1.0<f/f1<3.0 \quad (2)$$

$$2.03\text{ mm}<f<5.16\text{ mm} \quad (3)$$

$$1.0\text{ mm}<f1<3.0\text{ mm} \quad (4)$$

wherein f is the focal length of the entire lens system, fl is the focal length of the first lens, and TL is the distance along the optical axis from the surface of the first lens toward the object side to the paraxial focal point position at the image side, in which the portion corresponding to back focus is an air converted length.

In the imaging lens of the present disclosure, it is preferable for at least one of Conditional Formulae (1-1) through (5-2) below to be satisfied. Note that as a preferable aspect, one or arbitrary combinations of Conditional Formulae (1-1) through (5-2) may be satisfied.

$$0.9<TL/f<1.0 \quad (1\text{-}1)$$

$$1.2<f/f1<2.5 \quad (2\text{-}1)$$

$$1.7<f/f1<2.0 \quad (2\text{-}2)$$

$$0.003<Da/f<0.050 \quad (5)$$

$$0.004<Da/f<0.040 \quad (5\text{-}1)$$

$$0.005<Da/f<0.030 \quad (5\text{-}2)$$

wherein Da is the distance along the optical axis between the first lens and the second lens.

It is preferable for the imaging lens of the present disclosure to consist of six or fewer lenses.

In the imaging lens of the present disclosure, it is preferable for the surface of the second lens toward the image side to be a concave surface.

In the imaging lens of the present disclosure, it is preferable for a second negative lens from the object side to have a concave surface toward the object side, among negative lenses within the entire lens system.

In the imaging lens of the present disclosure, it is preferable for the lens most toward the image side to be a negative lens having a concave surface toward the image side.

In the imaging lens of the present disclosure, it is preferable for an aperture stop to be positioned at the object side of the surface of the second lens toward the object side.

In the imaging lens of the present disclosure, it is preferable for the surface toward the image side of the lens most toward the image side to be an aspherical surface having an inflection point, which is concave in the vicinity of the optical axis.

Among the lenses that constitute the imaging lens of the present disclosure, the plurality of lenses other than the first lens and the second lens may consist of three lenses including, in order from the object side to the image side, a third lens having a positive refractive power, a fourth lens having a negative refractive power, and a fifth lens having a negative refractive power.

Among the lenses that constitute the imaging lens of the present disclosure, the plurality of lenses other than the first lens and the second lens may consist of two lenses including, in order from the object side to the image side, a third lens having a positive refractive power and a fourth lens having a negative refractive power.

Among the lenses that constitute the imaging lens of the present disclosure, the plurality of lenses other than the first lens and the second lens may consist of four lenses including, in order from the object side to the image side, a third lens having a negative refractive power, a fourth lens having a positive refractive power, a fifth lens having a positive refractive power, and a sixth lens having a negative refractive power.

In the imaging lens of the present disclosure and the preferred configurations thereof, the term "consist(s) of" means that the imaging lens of the present disclosure may also include lenses that practically have no power, optical elements other than lenses such as a stop and a cover glass, and mechanical components such as lens flanges, a lens barrel, a camera shake correcting mechanism, etc., in addition to the lenses listed as constituent elements.

In addition, in the present disclosure, compound aspherical lenses (a lens constituted by a spherical lens and a film having an aspherical shape formed integrally on the spherical lens) are not considered to be cemented lenses, but are treated as single lenses.

Note that the shapes of the surfaces and the signs of the refractive powers of the lenses of the imaging lens of the present disclosure and the preferred configurations thereof are those in the vicinity of the optical axis (paraxial region) for lenses that include aspherical surfaces, unless otherwise noted.

An imaging apparatus of the present disclosure is equipped with the imaging lens of the present disclosure.

In the imaging lens of the present disclosure, a positive lens and a negative lens are provided as the first and second lenses in order from the object side, the imaging lens is constituted by four or more lenses, and configured to satisfy predetermined conditional formulae. Therefore, an imaging lens that can has a shortened the total length and high imaging performance which is compatible with an increased number of pixels, while maintaining an angle of view which is standard for portable terminals can be realized.

The imaging apparatus of the present disclosure is equipped with the imaging lens of the present disclosure. Therefore, photography is enabled with an angle of view which is standard for portable terminals, the size of the apparatus can be shortened in the direction of the optical axis of the imaging lens, and high resolution photographed images can be obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional diagram that illustrates a first example of the configuration of an imaging lens according to an embodiment of the present disclosure, and corresponds to a lens of Example 1.

FIG. **2** is a sectional diagram that illustrates a second example of the configuration of an imaging lens according to an embodiment of the present disclosure, and corresponds to a lens of Example 2.

FIG. **3** is a sectional diagram that illustrates a third example of the configuration of an imaging lens according to an embodiment of the present disclosure, and corresponds to a lens of Example 3.

FIG. **4** is a sectional diagram that illustrates a fourth example of the configuration of an imaging lens according to an embodiment of the present disclosure, and corresponds to a lens of Example 4.

FIG. **5** is a diagram that illustrates the paths of light rays that pass through the imaging lens of FIG. **1**.

FIG. **6** is a collection of diagrams that illustrate aberrations of the imaging lens of Example 1, wherein A illustrates spherical aberration, B illustrates astigmatism, C illustrates distortion, and D illustrates lateral chromatic aberration.

FIG. **7** is a collection of diagrams that illustrate aberrations of the imaging lens of Example 2, wherein A illustrates spherical aberration, B illustrates astigmatism, C illustrates distortion, and D illustrates lateral chromatic aberration.

FIG. **8** is a collection of diagrams that illustrate aberrations of the imaging lens of Example 3, wherein A illustrates spherical aberration, B illustrates astigmatism, C illustrates distortion, and D illustrates lateral chromatic aberration.

FIG. **9** is a collection of diagrams that illustrate aberrations of the imaging lens of Example 4, wherein A illustrates spherical aberration, B illustrates astigmatism, C illustrates distortion, and D illustrates lateral chromatic aberration.

FIG. **10** is a diagram that illustrates a cellular telephone as an imaging apparatus equipped with the imaging lens of the present disclosure.

FIG. **11** is a diagram that illustrates a smart phone as an imaging apparatus equipped with the imaging lens of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, embodiments of the present disclosure will be described in detail with reference to the attached drawings.

FIG. **1** illustrates a first example of the configuration of an imaging lens according to an embodiment of the present disclosure. This example corresponds to the lens configuration of Numerical Example 1 (Table 1 and Table 2), to be described later. Similarly, FIG. **2** through FIG. **4** are sectional diagrams that illustrate second through fourth examples of lens configurations that correspond to Numerical Examples 2 through 4 (Table 3 through Table 8). In FIGS. **1** through **4**, the symbol Ri represents the radii of curvature of ith surfaces (i=1, 2, 3 . . . ; to be described in detail later). The symbol Di represents the distances between an ith surface and an i+1 st surface along an optical axis Z**1**. Note that the basic configurations of the examples are the same, and therefore a description will be given of the imaging lens of FIG. **1** as a base, and the examples of FIGS. **2** through **4** will also be described as necessary. In addition, FIG. **5** is a diagram that illustrates the paths of light rays that pass through the imaging lens L of FIG. **1**. FIG. **5** illustrates the paths of axial light beams **2** and maximum angle of view light beams **3** from an object at a distance of infinity.

The imaging lens L of the embodiment of the present disclosure is favorably employed in various imaging devices that employ imaging elements such as a CCD and a CMOS. The imaging lens L of the embodiment of the present

disclosure is particularly favorable for use in comparatively miniature portable terminal devices, such as a digital still camera, a cellular telephone with a built in camera, a smart phone, a tablet type terminal, and a PDA.

FIG. **10** schematically illustrates a cellular telephone as an imaging apparatus **1** according to an embodiment of the present disclosure. The imaging apparatus **1** of the embodiment of the present disclosure is equipped with the imaging lens L according to the embodiment of the present disclosure and an imaging element **100** (refer to FIG. **1**) such as a CCD that outputs image signals corresponding to optical images formed by the imaging lens L. The imaging element **100** is provided such that the imaging surface thereof matches the position of an image formation plane Sim.

FIG. **11** schematically illustrates a smart phone as an imaging apparatus **501** according to an embodiment of the present disclosure. The imaging apparatus **501** of the embodiment of the present disclosure is equipped with a camera section **541** having the imaging lens L according to the embodiment of the present disclosure and an imaging element **100** (refer to FIG. **1**) such as a CCD that outputs image signals corresponding to optical images formed by the imaging lens L. The imaging element **100** is provided such that the imaging surface thereof matches the position of the image formation plane Sim.

The imaging lens L is constituted essentially by four or more lenses, which are, in order from the object side to the image side, a first lens L**1** having a positive refractive power, a second lens L**2** having a negative refractive power, and a plurality of other lenses. It is more advantageous from the viewpoint of improving performance to have a greater number of lenses. However, if increases in cost and spatial restrictions related to the shortening of the total length of the lens system are taken into consideration, it is preferable for the number of lenses that essentially constitute the entire lens system to be six or fewer.

For example, the imaging lens L may be constituted essentially by five lenses, which are, in order from the object side to the image side, a first lens L**1** having a positive refractive power, a second lens L**2** having a negative refractive power, a third lens L**3** having a positive refractive power, a fourth lens L**4** having a negative refractive power, and a fifth lens L**5** having a negative refractive power, as illustrated in FIG. **1** and FIG. **2**. Adopting such a five lens configuration is advantageous from the viewpoint of realizing both high performance and a shortening of the total length of the lens system.

Alternatively, the imaging lens L may be constituted essentially by four lenses, which are, in order from the object side to the image side, a first lens L**1** having a positive refractive power, a second lens L**2** having a negative refractive power, a third lens L**3** having a positive refractive power, and a fourth lens L**4** having a negative refractive power, as illustrated in FIG. **3**. Adopting such a four lens configuration is more advantageous from the viewpoint of realizing a shortening of the total length of the lens system and a decrease in cost.

As a further alternative, the imaging lens L may be constituted essentially by six lenses, which are, in order from the object side to the image side, a first lens L**1** having a positive refractive power, a second lens L**2** having a negative refractive power, a third lens L**3** having a negative refractive power, a fourth lens L**4** having a positive refractive power, a fifth lens L**5** having a positive refractive power, and a sixth lens L**6** having a negative refractive power, as illustrated in FIG. **4**. Adopting such a six lens configuration is more advantageous from the viewpoint of realizing high performance.

Various optical members CG may be provided between the lens provided most toward the image side and the imaging element **100**, depending on the configuration of the camera to which the lens is applied. A planar optical member such as a cover glass for protecting the imaging surface and an infrared cutoff filter may be provided, for example. In this case, a planar cover glass having a coating having a filtering effect such as an infrared cutoff filter coating or an ND filter coating, or a material that exhibits similar effects, may be utilized as the optical member CG.

Alternatively, the optical member CG may be omitted, and a coating may be administered on the lens to obtain the same effect as that of the optical member CG. In this case, the number of parts can be reduced, and the total length of the lens system can be shortened.

In the case that an aperture stop St is provided in the imaging lens L, it is preferable for the aperture stop St to be positioned at the object side of the surface of the second lens L**2** toward the object side. By positioning the aperture stop St at the object side of the surface of the second lens L**2** toward the object side in this manner, increases in the incident angles of light rays that pass through the optical system and enter the image formation plane Sim (that is, the imaging element **100**) can be suppressed, particularly at peripheral portions of an imaging region. It is more preferable for the aperture stop St to be positioned at the object side of the surface of the first lens L**1** toward the object side, in order to cause this advantageous effect to become more prominent.

Note that the aperture stops St illustrated in the FIG. **1** through FIG. **5** do not necessarily represent the sizes or shapes thereof, but indicate the positions thereof on the optical axis Z**1**. In addition, the expression "positioned at the object side of the surface of the second lens toward the object side" means that the position of the aperture stop St in the direction of the optical axis is at the same position as the intersection of marginal axial rays of light **2***m* (refer to FIG. **5**) and the surface of the second lens L**2** toward the object side, or more toward the object side than this position. Similarly, the expression "positioned at the object side of the surface of the first lens L**1** toward the object side" means that the position of the aperture stop in the direction of the optical axis is at the same position as the intersection of marginal axial rays of light **2***m* and the surface of the first lens L**1** toward the object side, or more toward the object side than this position.

In the examples of the configurations illustrated in FIG. **1** through FIG. **4**, the aperture stop St is positioned at the image side of the apex of the surface of the first lens L**1** toward the object side. However, the present disclosure is not limited to such a configuration, and the aperture stop St may be positioned at the object side of the apex of the surface of the first lens L**1** toward the object side. A case in which the aperture stop St is positioned at the object side of the apex of the surface of the first lens L**1** toward the object side is somewhat disadvantageous from the viewpoint of securing peripheral light intensity compared to a case in which the aperture stop St is positioned at the image side of the apex of the surface of the first lens L**1**. However, increases in the incident angles of light rays that pass through the optical system and enter the image formation plane (imaging element) can be further suppressed at the peripheral portions of the imaging region.

In the imaging lens L, the first lens L**1** has a positive refractive power in the vicinity of the optical axis. Thereby, the total length of the lens system can be favorably shortened. In addition, it is preferable for the first lens L**1** to have a convex surface toward the object side in the vicinity of the optical axis. In this case, the surface most toward the object side in the lens system will be of a convex shape. As a result, the position of the rearward principal point can be moved toward the object side, and the total length of the lens system can be favorably shortened.

The second lens L**2** has a negative refractive power in the vicinity of the optical axis. It is preferable for the second lens L**2** to have a concave surface toward the image side in the vicinity of the optical axis. In this case, the total length of the lens system can be favorably shortened, and spherical aberration can be favorably corrected.

It is preferable for the imaging lens L to have two or more negative lenses. In this case, the negative refractive power required in the entire lens system can be distributed, which is advantageous from the viewpoint of favorably correcting aberrations.

In the case that the imaging lens L has two or more negative lenses, it is preferable for the surface toward the object side of the second negative lens from the object side among the negative lenses of the entire lens system to be a concave surface in the vicinity of the optical axis. In this case, the total length of the lens system can be favorably shortened, and the generation of differences in spherical aberration depending on wavelength can be suppressed with respect to light rays of different wavelengths.

It is preferable for the lens provided most toward the image side to have a negative refractive power. In this case, a shortening of the total length of the lens system can be favorably realized. Further, it is preferable for the surface toward the image side of the lens provided most toward the image side to be concave in the vicinity of the optical axis. This configuration is further advantageous from the viewpoint of shortening the total length of the lens system.

It is preferable for the surface toward the image side of the lens most toward the image side to be of an aspherical shape having an inflection point within the effective diameter thereof. In this case, increases in the incident angles of light rays that pass through the optical system with respect to the imaging formation plane Sim (that is, the imaging element **100**) can be suppressed, particularly at peripheral portions of the imaging region. Note that here, “having an inflection point” means that the surface toward the image side of the lens most toward the image side has a point at which a curve formed by the cross section of the surface toward the image side of the lens most toward the image side within the effective diameter that includes the optical axis Z**1** changes from a convex shape to a concave shape (or from a concave shape to a convex shape).

It is favorable for at least one of the surfaces of all of the lenses within the entire lens system to be an aspherical surface, in order to improve performance.

In addition, it is preferable for all of the lenses that constitute the imaging lens L to be a single lens, not a cemented lens. In the case that all of the lenses that constitute the imaging lens L is a single lens, the number of aspherical lens surfaces will be greater than that for a case in which any of the lenses is a cemented lens. Therefore, the degree of freedom in the design of each lens will increase. As a result, the total length of the lens system can be favorably shortened.

In addition, in the case that the configurations of each of the lenses of the imaging lens L are set such that the full angle of view is 70 degrees or greater as in the example illustrated in FIG. **5**, the imaging lens L may be favorably applied to cellular telephone terminals and the like, which are often used for close distance photography. It is preferable for the imaging lens L to be configured such that the full angle of view is 70 degrees or greater for this reason.

Next, the operation and effects of conditional formulae related to the imaging lens L configured as described above will be described in greater detail. First, the imaging lens L is configured such that Conditional Formulae (1) through (4) below are satisfied.

$$0.8<TL/f<1.0 \tag{1}$$

$$1.0<f/fl<3.0 \tag{2}$$

$$2.03\text{ mm}<f<5.16\text{ mm} \tag{3}$$

$$1.0\text{ mm}<fl<3.0\text{ mm} \tag{4}$$

wherein f is the focal length of the entire lens system, fl is the focal length of the first lens, and TL is the distance along the optical axis from the surface of the first lens toward the object side to the paraxial focal point position at the image side, in which the portion corresponding to back focus is an air converted length.

Conditional Formula (1) defines a preferable range for the ratio of the total length of the lens system with respect to the focal length of the entire lens system. By securing the ratio of the total length of the lens system and the focal length of the entire lens system such that the value of TL/f is not less than or equal to the lower limit defined in Conditional Formula (1), it will be possible to correct various aberrations while maintaining a full angle of view which is standard for portable terminals and the like, approximately 70 degrees for example. As a result, it will become possible to realize high resolution. By suppressing the ratio of the total length of the lens system and the focal length of the entire lens system such that the value of TL/f is not greater than or equal to the upper limit defined in Conditional Formula (1), the length of the lens system as a whole can be shortened in the direction of the optical axis.

By configuring the imaging lens such that Conditional Formula (1) is satisfied, it will be possible to correct various aberrations while maintaining a full angle of view which is standard for portable terminals and the like, approximately 70 degrees for example, thereby realizing high resolution, and the total length of the lens system as a whole can be shortened. It is more preferable for Conditional Formula (1-1) to be satisfied, in order to cause these advantageous effects to become more prominent.

$$0.9<TL/f<1.0 \tag{1-1}$$

Conditional Formula (2) defines a preferable range for the ratio of the focal length of the entire lens system with respect to the focal length of the first lens L**1**. That is, Conditional Formula (2) defines a preferable range of numerical values for the ratio of the refractive power of the first lens L**1** with respect to the refractive power of the entire lens system. By securing the positive refractive power of the first lens L**1** such that the value of f/fl is not less than or equal to the lower limit defined in Conditional Formula (2), a shortening of the total length of the lens system can be favorably realized. By suppressing the positive refractive power of the first lens L**1** such that the value of f/fl is not greater than or equal to the upper limit defined in Conditional Formula (2), correction of spherical aberration and astigmatism will be facilitated.

By configuring the lens provided most toward the object side to be a positive lens, and by allotting an amount of

positive refractive power to this positive lens such that Conditional Formula (2) is satisfied, a shortening of the total length of the lens system can be favorably achieved, while spherical aberration and astigmatism can be favorably corrected. It is more preferable for Conditional Formula (2-1) to be satisfied, and even more preferable for Conditional Formula (2-2) to be satisfied, in order to cause these advantageous effects to become more prominent.

$$1.2<f/fl<2.5 \tag{2-1}$$

$$1.7<f/fl<2.0 \tag{2-2}$$

Conditional Formula (3) defines a preferable range for the focal length of the entirety of a compact lens system which is favorably suited for portable terminals and the like. By setting the focal length of the entire lens system such that the value of f is not less than or equal to the lower limit defined in Conditional Formula (3), a predetermined total length can be secured for the lens system. As a result, a number of lenses capable of favorably correcting aberrations, as well as a cover glass, filters, etc. may be provided. By setting the focal length of the entire lens system such that the value of f is not greater than or equal to the upper limit defined in Conditional Formula (3), the total length of the lens system can be suppressed, and a compact lens system which is favorably suited for portable terminals and the like can be realized. By configuring the imaging lens such that Conditional Formula (3) is satisfied, space for providing optical components that enable obtainment of images having high image quality can be secured, while realizing a compact lens system which is favorably suited for portable terminals and the like.

Note that the ratio of the total length of the lens system with respect to the focal length of the entire lens system can be maintained within a predetermined range by Conditional Formula (1) being satisfied. However, by Conditional Formula (3) being further satisfied in addition to Conditional Formula (1), the actual dimensions of the total length of the lens system can be maintained within a predetermined range. As a result, it will be possible to satisfy demand for both high performance and miniaturization, which is required of imaging lenses to be mounted on recent portable terminals and the like.

Conditional Formula (4) defines a preferable range for the focal length of the first lens L**1** in a compact lens system which is favorably suited for portable terminals and the like. By suppressing the refractive power of the first lens L**1** such that the value of fl is not less than or equal to the lower limit defined in Conditional Formula (4), correction of spherical aberration and astigmatism will be facilitated. By securing the refractive power of the first lens L**1** such that the value of fl is not greater than or equal to the upper limit defined in Conditional Formula (4), a shortening of the total length of the lens system can be favorably realized. By configuring the lens system such that Conditional Formula (4) is satisfied, a shortening of the total length can be achieved, while spherical aberration and astigmatism can be favorably corrected.

By configuring the imaging lens such that Conditional Formula (2) is satisfied in addition to Conditional Formulae (3) and (4), high resolution can be achieved, while a compact lens system which is favorably suited for portable terminals and the like can be realized. In addition, by Conditional Formulae (1) through (4) being satisfied at the same time, a lens system having high resolution and a shortened total length can be realized, while maintaining a full angle of view which is standard for portable terminals and the like, 70 degrees for example.

In addition, it is preferable for Conditional Formula (5) to be satisfied in the imaging lens L.

$$0.003<Da/f<0.050 \tag{5}$$

wherein Da is the distance along the optical axis from the first lens to the second lens.

Da corresponds to the distance D**3** in the example illustrated in FIG. **1**. Conditional Formula (5) defines a preferable range for the ratio of the distance between the first lens L**1** and the second lens L**2** with respect to the focal length of the entire lens system. By securing the distance between the first lens L**1** and the second lens L**2** such that the value of Da/f is not less than or equal to the lower limit defined in Conditional Formula (5), the distance between the first lens L**1** and the second lens L**2** becoming short and causing assembly to become difficult can be prevented. Suppressing the distance between the first lens L**1** and the second lens L**2** such that the value of Da/f is not greater than or equal to the upper limit defined in Conditional Formula (5) is advantageous from the viewpoint of shortening the total length of the lens system.

By configuring the imaging lens such that Conditional Formula (5) is satisfied, the total length of the lens system can be favorably shortened, while a deterioration in productivity can be suppressed. It is more preferable for Conditional Formula (5-1), and even more preferable for Conditional Formula (5-2) to be satisfied, in order to cause these advantageous effects to become more prominent.

$$0.004<Da/f<0.040 \tag{5-1}$$

$$0.005<Da/f<0.030 \tag{5-2}$$

Note that arbitrary combinations of the preferred configurations described above are possible. It is preferable for the preferred configurations to be selectively adopted as appropriate according on specifications required of the imaging lens.

Next, specific examples of numerical values of the imaging lens of the present disclosure will be described. A plurality of examples of numerical values will be summarized and explained below.

Table 1 and Table 2 below show specific lens data corresponding to the configuration of the imaging lens illustrated in FIG. **1**. Table 1 shows basic lens data of the imaging lens, and Table 2 shows data related to aspherical surfaces. In the lens data of Table 1, ith lens surface numbers that sequentially increase from the object side to the image side, with the surface of the aperture stop St designated as first and the lens surface at the most object side (the surface of the first lens L**1** toward the object side) designated as second, are shown in the column Si for the imaging lens of Example 1. The radii of curvature (mm) of ith surfaces from the object side corresponding to the symbols Ri illustrated in FIG. **1** are shown in the column Ri. Similarly, the distances (mm) between an ith surface Si and an i+1st surface Si+1 from the object side along the optical axis are shown in the column Di. The refractive indices of jth optical elements from the object side with respect to the d line (wavelength: 587.56 nm) are shown in the column Ndj. The Abbe's numbers of the jth optical elements with respect to the d line are shown in the column νdj.

Note that the signs of the radii of curvature are positive in cases that the surface shape is convex toward the object side, and negative in cases that the surface shape is convex toward the image side. The signs of the distances between surfaces are positive in cases that the direction from a surface Si toward a surface Si+1 is from the object side to the image

side, and negative in cases that the direction from a surface Si toward a surface Si+1 is from the image side to the object side. Table 1 shows data related to the imaging lens and the optical member CG.

Note that the focal length f of the entire lens system (mm), the F number Fno, the full angle of view 2ω (°), and the total length TL (mm) of the lens system are shown as various items of data above the frame of Table 1. Note that the total length TL of the lens system is the distance along the optical axis from the surface of the first lens L**1** toward the object side to the position of a paraxial focal point at the image side, in which the portion corresponding to the back focus Bf is an air converted value.

In the imaging lens of Example 1, both of the surfaces of the first lens L**1** through the fifth lens L**5** are all aspherical in shape. In the basic lens data of Table 1, numerical values of radii of curvature in the vicinity of the optical axis (paraxial radii of curvature) are shown as the radii of curvature of the aspherical surfaces.

Table 2 shows aspherical surface data of the imaging lens of Example 1. In the numerical values shown as the aspherical surface data, the symbol "E" indicates that the numerical value following thereafter is a "power index" having 10 as a base, and that the numerical value represented by the index function having 10 as a base is to be multiplied by the numerical value in front of "E". For example, "1.0E-02" indicates that the numerical value is "$1.0\cdot10^{-2}$".

The values of coefficients An and K represented by the aspherical surface shape formula (A) below are shown as the aspherical surface data. In greater detail, Z is the length (mm) of a normal line that extends from a point on the aspherical surface having a height h to a plane (a plane perpendicular to the optical axis) that contacts the apex of the aspherical surface.

$$Z = \frac{C \times h^2}{1 + \sqrt{1 - (1 + K) \times C^2 \times h^2}} + \sum_n An \times h^n \tag{A}$$

wherein: Z is the depth of the aspherical surface (mm), h is the distance from the optical axis to the surface of the lens (height) (mm), C is the paraxial curvature=1/R (R is the paraxial radius of curvature), An is an nth ordinal aspherical surface coefficient (n is an integer 4 or greater and 16 or less), and K is a conic constant.

Specific lens data corresponding to the configuration of the imaging lens illustrated in FIG. **2** are shown in Table 3 and Table 4 as Example 2. Similarly, specific lens data corresponding to the configurations of the imaging lenses illustrated in FIG. **3** and FIG. **4** are shown in Table 5 through Table 8 as Example 3 and Example 4. The aspherical surface coefficient n of the second through fifth surfaces of Example 3 and all of the aspherical surfaces of Example 4 are even numbers 4 or greater and 14 or less. In the imaging lenses of Example 1 through Example 4, both of the surfaces of all of the lenses are aspherical surfaces.

A through D of FIG. **6** are diagrams that illustrate aberrations of the imaging lens of Example 1, that respectively illustrate the spherical aberration, the field curvature, the distortion, and the lateral chromatic aberration (chromatic aberration of magnification). Each of the diagrams that illustrate the spherical aberration and the field curvature illustrate aberrations related to the d line (wavelength: 587.56 nm), the F line (wavelength: 486.1 nm), and the C line (wavelength: 656.27 nm). The diagram that illustrates lateral chromatic aberration shows aberrations related to the F line and the C line, with the d line as a reference wavelength. In the diagram that illustrates field curvature, (S) denotes aberration in the sagittal direction, and (T) denotes aberration in the tangential direction.

Similarly, the aberrations of the imaging lens of Example 2 through Example 4 are illustrated in A through D of FIG. **7** through A through D of FIG. **9**. The diagrams that illustrate aberrations of A through D of FIG. **6** through A through D of FIG. **9** are all for cases in which the object distance is infinity.

In addition, Table 9 shows values corresponding to Conditional Formulae (1) through (5), respectively summarized for each of Examples 1 through 4. The values shown in Table 9 are those related to the d line.

As can be understood from each set of numerical value data and from the diagrams that illustrate aberrations, the imaging lenses of Examples 1 through 4 have full angles of view within a range from 70 degrees to 75 degrees, and the total lengths TL of the lens systems are within a range from 3.1 mm to 4.0 mm. That is, a shortening of the total length of the lens system is achieved while maintaining a full angle of view which is standard for portable terminals. Further, various aberrations are favorably corrected, and high imaging performance is realized.

Note that the imaging lens of the present disclosure is not limited to the embodiments and Examples described above, and various modifications are possible. For example, the values of the radii of curvature, the distances among surfaces, the refractive indices, the Abbe's numbers, the aspherical surface coefficients, etc., are not limited to the numerical values indicated in connection with the Examples of numerical values, and may be other values.

In addition, the Examples are described under the presumption that they are to be utilized with fixed focus. However, it is also possible for configurations capable of adjusting focus to be adopted. It is possible to adopt a configuration, in which the entirety of the lens system is fed out or a portion of the lenses is moved along the optical axis to enable automatic focus, for example.

Example 1

TABLE 1

f = 4.01, Fno. = 2.6, 2ω = 72.0, TL = 3.95

Si	Ri	Di	Ndj	νdj
1 (aperture stop)	∞	−0.240000		
*2	1.248186	0.510022	1.544884	54.87
*3	−55.853797	0.023815		
*4	−71.457835	0.297217	1.633506	23.63
*5	2.589265	0.641525		
*6	−26.018306	0.107756	1.544884	54.87
*7	−4.887691	0.550329		
*8	−4.378748	0.317276	1.633506	23.63
*9	−4.502550	0.254989		
*10	3.275584	0.462402	1.544884	54.87
*11	1.123792	0.202904		
12	∞	0.145000	1.516330	64.14
13	∞	0.483940		
14 (imaging surface)	∞			

*aspherical surface

TABLE 2

Surface Number	KA	A3	A4	A5	A6
2	−1.3212468E+01	−3.2010292E−02	9.7127463E−01	−4.1441026E−01	−2.9581230E+00
3	−2.2162782E+02	−4.6939205E−02	3.5840007E−01	−7.1668262E−01	−3.0196076E−01
4	−7.7774382E+02	4.4862926E−02	−2.3154381E−02	8.9262055E−02	9.9153816E−01
5	8.7876118E+00	5.3914158E−02	−1.2205780E−01	3.3623397E−01	4.7272146E−01
6	7.1848813E+02	−7.4332479E−02	2.2903737E−01	−8.6386820E−01	8.8480140E−01
7	−1.4448115E+02	−1.4680435E−02	−3.2247983E−01	1.0341382E+00	−2.6759111E+00
8	−7.2899625E+02	1.5237198E−01	−1.0965089E+00	2.6778406E+00	−2.4488360E+00
9	2.0001892E+00	−1.5857648E−01	8.3863492E−01	−1.7144932E+00	1.4227139E+00
10	−3.6747110E+01	−3.3308330E−01	1.3075487E−01	−5.4611043E−01	6.2320857E−01
11	−2.8825648E+00	−1.6713971E−01	−9.9582938E−01	2.7129347E+00	−3.7539111E+00

Surface Number	A7	A8	A9	A10	A11
2	5.7748718E+00	−4.7691207E+00	4.1977000E+00	−3.4405023E+00	−5.0000669E+00
3	3.2844684E+00	−4.1040752E+00	−9.6045412E−01	2.9706036E+00	3.5660330E+00
4	−4.4232849E+00	7.5497582E+00	−5.8084122E+00	4.8872207E+00	−1.4014084E+01
5	−3.2661042E+00	6.3848549E+00	−6.4401676E+00	7.8102425E−01	1.3210099E+01
6	6.0051486E−01	−2.4844103E+00	1.5427055E+00	1.0603798E−01	3.6771996E−01
7	2.3215258E+00	1.9188104E+00	−4.4289849E+00	6.1619829E−01	2.1371523E+00
8	−5.3397685E−01	1.9192393E+00	−8.3305954E−01	1.0221456E+00	−1.3006852E+00
9	9.6055840E−01	−3.3196842E+00	2.1873641E+00	6.9881886E−01	−9.5523496E−01
10	−1.5717115E−01	−8.0713763E−02	3.5601990E−03	4.3398861E−02	1.1828531E−02
11	2.7630021E+00	−6.1241496E−01	−4.7567270E−01	2.6601539E−01	1.9427965E−02

Surface Number	A12	A13	A14	A15	A16
2	9.4270649E+00	2.8026655E+00	−1.3048820E+01	7.9609525E+00	−1.3947121E+00
3	−2.1148237E+00	−9.0816066E+00	3.3006462E+00	1.1218064E+01	−7.6278734E+00
4	2.2137640E+01	−1.3506303E+01	−1.3686354E+00	5.8899674E+00	−2.2744994E+00
5	−2.5460608E+01	1.9589246E+01	−1.2172121E+01	1.7384456E+01	−1.1580743E+01
6	−1.1006658E+00	−7.2761073E−01	3.4862697E+00	−2.6978835E+00	4.7921100E−01
7	−8.1536404E−01	−6.4668408E−01	9.4854860E−01	4.7417804E−01	−7.7570745E−01
8	2.1641923E−01	−3.7471065E−01	1.0564631E+00	−6.2773999E−01	1.0266054E−01
9	−3.5502699E−01	3.4672168E−01	1.8713235E−01	−1.7830886E−01	3.3141578E−02
10	−3.2945535E−02	1.3873446E−02	−2.9634561E−03	9.0292501E−04	−1.8653823E−04
11	−6.3524204E−03	−3.5187945E−02	2.2802501E−02	−6.1163617E−03	6.8179272E−04

Example 2

TABLE 3

f = 4.02, Fno. = 2.4, 2ω = 70.8, TL = 3.97

Si	Ri	Di	Ndj	νdj
1 (aperture stop)	∞	−0.290000		
*2	1.266094	0.672786	1.544884	54.87
*3	−151.018032	0.030338		
*4	−441.388916	0.240335	1.613946	25.30
*5	2.717418	0.554476		
*6	6.431903	0.098014	1.544884	54.87
*7	18.042506	0.648699		

TABLE 3-continued

f = 4.02, Fno. = 2.4, 2ω = 70.8, TL = 3.97

Si	Ri	Di	Ndj	νdj
*8	−2.378787	0.361894	1.633506	23.63
*9	−2.916855	0.163203		
*10	2.379858	0.409109	1.544884	54.87
*11	1.225990	0.171307		
12	∞	0.145000	1.516330	64.14
13	∞	0.483940		
14 (imaging surface)	∞			

*aspherical surface

TABLE 4

Surface Number	KA	A3	A4	A5	A6
2	−1.3546683E+01	−2.0041001E−02	8.6320095E−01	−2.9687864E−01	−2.5818222E+00
3	−6.3866451E+07	−8.8479843E−03	−6.4169722E−02	1.3285020E−02	−8.8665570E−01
4	2.2470738E+05	3.8738636E−02	−3.0129213E−01	1.9466058E−01	1.4344934E+00
5	3.4852098E+00	9.7704874E−02	−5.1831249E−01	1.5985440E+00	−1.6955204E+00
6	−8.5496409E+01	1.2466183E−02	8.8808820E−02	−1.5849718E+00	3.3974575E+00
7	8.8779349E+01	7.3567526E−02	−4.4257981E−01	4.1835366E−01	−4.2270092E−01
8	−1.0719832E+01	7.6862426E−01	−2.5920829E+00	4.0456408E+00	−3.3570112E+00
9	−1.1522838E+00	−4.1481437E−01	6.0247471E−01	8.5552085E−01	−4.0439369E+00
10	−6.6918911E+02	−2.6029840E−01	2.7017015E−01	−5.2969360E−01	5.1395184E−01
11	−4.2956928E+00	4.6365066E−02	−1.1736117E+00	2.7424446E+00	−3.5662791E+00

TABLE 4-continued

Surface Number	A7	A8	A9	A10	A11
2	5.1200952E+00	−4.8728445E+00	4.5573540E+00	−2.9231769E+00	−4.9030421E+00
3	3.4085238E+00	−3.5149634E+00	−6.9741276E−01	1.5395929E+00	1.8327304E+00
4	−4.5521078E+00	7.1187545E+00	−6.1302094E+00	5.5764031E+00	−1.3422099E+01
5	−1.4874360E+00	6.5948462E+00	−7.1375197E+00	1.6899587E−01	1.3365746E+01
6	−2.2867433E+00	−2.3581269E+00	4.5915662E+00	−6.4550741E−01	−2.7520832E+00
7	7.1109144E−01	−1.0563681E+00	8.0860025E−01	8.4524672E−01	−1.9182657E+00
8	1.4653598E+00	−2.6051260E−01	−7.2410680E−01	1.7154157E+00	−1.4975887E+00
9	6.0501328E+00	−4.0794704E+00	4.5573227E−01	8.5557936E−01	−2.6728092E−01
10	−1.4671011E−01	−7.7832188E−02	7.2591237E−03	4.4414319E−02	1.1539501E−02
11	2.5522401E+00	−5.8974927E−01	−4.1209643E−01	2.5474436E−01	9.1290136E−03

Surface Number	A12	A13	A14	A15	A16
2	8.7072644E+00	2.2065169E+00	−1.2733195E+01	9.4659592E+00	−2.3930643E+00
3	−2.0865169E−01	−5.0269022E+00	4.2580693E+00	−1.4139627E−01	−6.9516215E−01
4	2.1410176E+01	−1.4507410E+01	−1.7254451E+00	8.5122925E+00	−3.7595037E+00
5	−2.3684995E+01	1.9389845E+01	−1.1630677E+01	9.9051184E+00	−4.7152887E+00
6	8.7646059E−01	1.0946236E+00	−2.8524021E−01	−4.4273006E−01	1.8228365E−01
7	6.0526646E−02	2.3608540E+00	−2.1787786E+00	7.4005688E−01	−8.1801266E−02
8	2.2671012E−01	5.9375322E−03	8.7347247E−01	−9.5422498E−01	2.9178978E−01
9	−1.4931670E−01	1.0069879E−01	1.7219549E−02	−5.3428722E−02	1.9941941E−02
10	−3.2936281E−02	1.3881989E−02	−2.9993178E−03	8.9292760E−04	−1.8308586E−04
11	−7.3661116E−03	−3.4038453E−02	2.3396624E−02	−6.0983398E−03	5.9611963E−04

Example 3

TABLE 5

f = 3.28, Fno. = 2.9, 2ω = 71.0, TL = 3.16

Si	Ri	Di	Ndj	νdj
1 (aperture stop)	∞	−0.150000		
*2	0.904212	0.430212	1.54	56.5
*3	15.379767	0.049238		
*4	−3.541585	0.154405	1.63	23.4
*5	5.812080	0.649693		
*6	−1.353189	0.266346	1.54	56.5

TABLE 5-continued

f = 3.28, Fno. = 2.9, 2ω = 71.0, TL = 3.16

Si	Ri	Di	Ndj	νdj
*7	−0.986605	0.452364		
*8	−6.699546	0.305318	1.53	55.8
*9	1.732706	0.199933		
10	∞	0.300000	1.52	64.2
11	∞	0.414000		
12 (imaging surface)	∞			

*aspherical surface

TABLE 6

Surface Number	KA	A4	A6	A8
2	−2.5364831E−01	−7.7531180E−02	1.2291438E+00	−7.8086978E+00
3	5.4910111E+02	−7.7916259E−02	1.1580918E+00	−8.0037672E+00
4	−1.7746510E+02	3.6184422E−01	1.7638199E−01	−3.3506962E+00
5	5.6802279E+01	9.4031723E−01	−1.7346081E+00	4.1298659E+00
6	−3.8980496E+00	−2.9718521E−01	−5.1341042E−02	−1.3962850E+00
7	−2.2456465E+00	−1.5497952E−01	−1.1631991E−01	−8.2951567E−01
8	−5.6571673E+02	−5.7255470E−01	2.1662849E−01	4.7834559E−02
9	−2.4328185E+00	−5.2468297E−01	3.5563560E−01	−1.7762108E−01

Surface Number	A10	A12	A14	A16
2	2.5493056E+01	−3.9257511E+01	1.0109932E+01	—
3	−3.2910059E+00	4.8825625E+01	−5.3320887E+01	—
4	−1.4906025E+01	6.4462794E+01	−4.4088031E+01	—
5	2.8621841E+00	−4.0818628E+01	8.9829881E+01	—
6	−5.5220011E+00	1.0096910E+01	4.2807378E+01	−9.3219929E+01
7	4.9274804E−01	1.0709023E+00	7.4971290E−01	−1.5027177E+00
8	−1.4041772E−02	−5.6061872E−03	−8.8286172E−04	3.5631882E−04
9	4.0696121E−02	9.3405871E−04	−1.9104675E−03	−3.8773448E−05

Example 4

TABLE 7

f = 4.00, Fno. = 2.8, 2ω = 71.2, TL = 3.89

Si	Ri	Di	Ndj	νdj
1 (aperture stop)	∞	−0.210000		
*2	1.152778	0.303593	1.51	56.8
*3	10.159658	0.077275		
*4	6.219245	0.104330	1.65	21.4
*5	2.353031	0.354965		
*6	−8.266512	0.123829	1.63	23.8
*7	−9.893200	0.643763		
*8	−7.130996	0.292307	1.54	55.9
*9	−2.086276	0.534767		
*10	−1.378463	0.183911	1.54	55.9
*11	−0.920547	0.233322		
*12	−1.368934	0.148256	1.54	55.9
*13	2.390504	0.197715		
14	∞	0.210000	1.52	64.2
15	∞	0.483000		
16 (imaging surface)	∞			

*aspherical surface

TABLE 8

Surface Number	KA	A4	A6	A8
2	−3.6867724E+00	3.1176600E−01	−1.4930332E−01	1.7504183E−01
3	1.0606410E+02	−3.8781814E−02	2.0910481E−01	−1.9854100E−01
4	−1.7515826E+02	1.1785485E−01	1.1554505E−01	3.6431461E−01
5	5.0856043E+00	3.5888263E−02	1.8292402E−01	5.4039908E−02
6	−4.5000559E+02	−4.2967593E−01	−7.8724390E−02	3.1271252E−01
7	8.9111829E+01	−3.0460387E−01	−1.2351341E−01	2.5016114E−01
8	5.1118472E+01	−9.6634327E−02	−4.4717695E−02	−2.4893022E−01
9	1.9974438E+00	−3.3887166E−03	7.9466818E−03	−1.8748970E−01
10	8.6332365E−02	7.9464707E−02	−2.7323299E−04	−5.7513127E−03
11	−5.4955726E+00	−1.0388535E−01	1.2895780E−01	−1.2652192E−01
12	−1.1130744E+01	−1.0314252E−01	−8.3726210E−03	1.4326135E−02
13	−5.8582439E+01	−9.2038345E−02	1.5566690E−02	−4.8717366E−03

Surface Number	A10	A12	A14
2	−8.5732546E−02	1.6208774E−01	−3.0035684E−01
3	−1.2898235E−01	1.2956948E−01	−2.8085047E−01
4	−1.1770860E+00	1.0492300E+00	−6.1806181E−01
5	−3.4390106E−01	5.0461465E−01	4.1455242E−01
6	−4.3734148E−01	1.0916784E+00	9.5251613E−01
7	2.6149050E−03	2.5484908E−01	5.3657077E−01
8	8.9553971E−02	1.2207775E−02	−5.4313761E−03
9	6.5975151E−02	3.8594080E−02	2.1027712E−03
10	6.1913902E−03	5.6036573E−03	−3.1744398E−03
11	6.6704873E−02	−1.8282427E−02	1.7661958E−03
12	−1.0472867E−03	−2.4046169E−04	−6.5030890E−06
13	1.5445189E−03	−3.6152741E−04	1.5330880E−05

TABLE 9

Values Related to Conditional Formulae

Formula	Condition	Example 1	Example 2	Example 3	Example 4
(1)	TL/f	0.99	0.99	0.96	0.97
(2)	f/f1	1.79	1.74	1.87	1.60
(3)	f	4.01	4.02	3.28	4.00
(4)	f1	2.25	2.31	1.75	2.50
(5)	Da/f	0.006	0.008	0.015	0.019

What is claimed is:

1. An imaging lens consisting of five lenses, including, in order from the object side to the image side:

a first lens having a positive refractive power;

a second lens having a negative refractive power;

a third lens having a positive refractive power;

a fourth lens having a negative refractive power; and

a fifth lens having a negative refractive power;

an aperture stop being positioned at the object side of the surface toward the object side of the first lens; and

the conditional formulae below being satisfied:

$$0.8<TL/f<1.0 \tag{1}$$

$$1.0<f/f1<3.0 \tag{2}$$

$$2.03\text{ mm}<f<5.16\text{ mm} \tag{3}$$

$$1.0\text{ mm}<f1<3.0\text{ mm} \tag{4}$$

wherein f is the focal length of the entire lens system, fl is the focal length of the first lens, and TL is the distance along the optical axis from the surface of the first lens toward the object side to the paraxial focal point position at the image side in the case that the portion corresponding to back focus is an air converted length.

2. An imaging lens as defined in claim 1, in which the conditional formula below is further satisfied:

$$0.003<Da/f<0.050 \tag{5}$$

wherein Da is the distance along the optical axis between the first lens and the second lens.

3. An imaging lens as defined in claim 1, wherein:

the surface of the second lens toward the image side is a concave surface.

4. An imaging lens as defined in claim 1, wherein:

a second negative lens from the object side from among negative lenses within the entire lens system has a concave surface toward the object side.

5. An imaging lens as defined in claim **1**, wherein:

the lens most toward the image side to be a negative lens has a concave surface toward the image side.

6. An imaging lens as defined in claim **1**, wherein:

the surface toward the image side of the lens most toward the image side is an aspherical surface having an inflection point, which is concave in the vicinity of the optical axis.

7. An imaging lens as defined in claim **1**, in which the conditional formula below is further satisfied:

$$0.9<TL/f<1.0 \quad (1\text{-}1).$$

8. An imaging lens as defined in claim **1**, in which the conditional formula below is further satisfied:

$$1.2<f/fl<2.5 \quad (2\text{-}1).$$

9. An imaging lens as defined in claim **1**, in which the conditional formula below is further satisfied:

$$1.7<f/fl<2.0 \quad (2\text{-}2).$$

10. An imaging lens as defined in claim **1**, in which the conditional formula below is further satisfied:

$$0.004<Da/f<0.040 \quad (5\text{-}1)$$

wherein Da is the distance along the optical axis between the first lens and the second lens.

11. An imaging lens as defined in claim **1**, in which the conditional formula below is further satisfied:

$$0.005<Da/f<0.030 \quad (5\text{-}2)$$

wherein Da is the distance along the optical axis between the first lens and the second lens.

12. An imaging apparatus comprising the imaging lens as defined in claim **1**.

13. An imaging lens consisting of four lenses, including, in order from the object side to the image side:

a first lens having a positive refractive power;

a second lens having a negative refractive power;

a third lens having a positive refractive power; and

a fourth lens having a negative refractive power;

an aperture stop being positioned at the object side of the surface toward the object side of the first lens; and

the conditional formulae below being satisfied:

$$0.8<TL/f<1.0 \quad (1)$$

$$1.0<f/fl<3.0 \quad (2)$$

$$2.03\text{ mm}<f<5.16\text{ mm} \quad (3)$$

$$1.0\text{ mm}<fl<3.0\text{ mm} \quad (4)$$

wherein f is the focal length of the entire lens system, fl is the focal length of the first lens, and TL is the distance along the optical axis from the surface of the first lens toward the object side to the paraxial focal point position at the image side in the case that the portion corresponding to back focus is an air converted length.

14. An imaging apparatus comprising the imaging lens as defined in claim **13**.

15. An imaging lens consisting of six lenses, including, in order from the object side to the image side:

a first lens having a positive refractive power;

a second lens having a negative refractive power; and

four lenses;

an aperture stop being positioned at the object side of the surface toward the object side of the first lens; and

the conditional formulae below being satisfied:

$$0.8<TL/f<1.0 \quad (1)$$

$$1.0<f/fl<3.0 \quad (2)$$

$$2.03\text{ mm}<f<5.16\text{ mm} \quad (3)$$

$$1.0\text{ mm}<fl<3.0\text{ mm} \quad (4)$$

$$0.004<Da/f<0.040 \quad (5\text{-}1)$$

wherein f is the focal length of the entire lens system, fl is the focal length of the first lens, TL is the distance along the optical axis from the surface of the first lens toward the object side to the paraxial focal point position at the image side in the case that the portion corresponding to back focus is an air converted length, and Da is the distance along the optical axis between the first lens and the second lens.

16. An imaging lens as defined in claim **15**, wherein the four lenses, which are, in order from the object side to the image side:

a third lens having a negative refractive power;

a fourth lens having a positive refractive power;

a fifth lens having a positive refractive power; and

a sixth lens having a negative refractive power.

17. An imaging apparatus comprising the imaging lens as defined in claim **15**.

* * * * *

The Optics of Miniature Digital Camera Modules

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ABSTRACT

Designing lenses for cell phone cameras is different from designing for traditional imaging systems; the format poses unique challenges. Most of the difficulty stems from the scale of the system, which is based on the size of the sensor.

Keywords: Optical design, lens design, digital cameras

1. INTRODUCTION

The scale of cell phone camera systems creates particular challenges for the lens designer that are unique to this format. Both the size and the low-cost requirements have many implications for the design, fabrication and assembly processes.

Fig.1: This 3.6um pixel VGA camera module is 6.05 x 6.05 x 4.5 mm.
The most critical dimension is the 4.5 mm axial length.

For those of us who have been involved in the design and manufacturing of consumer and commercial imaging systems using lens elements with diameters in the 12-40mm range, the switch to much smaller elements with diameters in the 3-5mm range takes some adjustment. When designing a camera module lens, it is not always helpful to begin with a traditional larger-scale imaging lens. Scaling down such a lens will result in a system that is unmanufacturable. If the design includes molded plastic optics, a scaled down system will result in element edge thicknesses shrinking to the point where the flow of plastic is affected. For glass elements, the edge thicknesses will become too thin to be fabricated without chipping. To achieve a successful design we have to modify our lens forms and adjust the proportions of the elements.

Layout drawings can be very misleading. Many times we find ourselves surprised when the mechanical layout of a lens barrel that looked reasonable on paper turns out to be very difficult or impossible to fabricate. Tabs on a barrel that appear substantial in a drawing, are found to be too flimsy to function on the actual part, "sharp" edges on molded stops don't fill completely because the features are too small. The size of the lenses and mechanical details on the flanges and barrels affect all aspects of the manufacturing process. Diamond tools have to be redesigned to be able to generate large changes in angle over small areas. Handling the lenses becomes difficult even with tweezers, all inspection and screening has to be done with a microscope. Measuring basic dimensions and the surfaces of the lenses becomes very challenging. Center thickness and surface decenter measurements in particular are difficult at the high levels of accuracy required for current designs. The ability to fabricate accurate and robust fixtures for measurement of individual elements has become absolutely critical.

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Another process that has been affected is assembly. Assembly must be done in clean conditions, with visual aids to ensure proper lens orientation and seating. Once an assembly is complete it needs to be tested. Testing assemblies with barrel outer dimensions of 6mm pose similar fixturing challenges as those in the fixturing of individual elements, with the additional requirement that they must be aligned with a test target for MTF or resolution testing. This target or series of targets must provide adequate sampling over an area representing the sensor, to characterize the lens, which could be anywhere from 1/10" diagonal to 1/3" diagonal. Fixturing for both MTF testing and resolution testing must minimize tilt of the lens barrel with respect to the target.

2. CMOS Focal Planes

Development of sensors has been moving steadily towards smaller pixels and higher density formats. The initial cell phone cameras were based around VGA and QVGA modules with 5.6um pixels. Generally formats were between 1/7" and ¼" in size. Next, the sensor manufacturers began offering VGA and SXGA sensors with 3.2-3.8um pixels in 1/6-1/4" formats. Then the sensors moved to 2.8um pixels offered in VGA, 1.3MP and 2MP, 1/8", ¼" and 1/3" formats respectively, a full 50% reduction in pixel size from the original sensors. Today we are designing for 2-3MP sensors in 2.2um pixels, ¼" and 1/3" formats, and there are plans for 5MP sensors with 1.75um(!) pixels coming soon.

Over the past couple of years, pixel areas have been reduced by 75%, then 85%, soon to be 90%, compared with 5.6 micron pixels. Lower pixel count formats (VGA and 1.3mp) have gotten correspondingly smaller, and higher resolution sensors (2mp and 3mp) have been introduced. The higher resolution formats have made the job of the lens designer extremely challenging because, while the basic imaging problem has remained the same, each reduction in pixel size has required an increase in lens performance,, and the overall length of the system is often required to be shorter. VGA systems pose different, but no less daunting problems. VGA sensors have scaled with the pixel size from ¼" with the original 5.6um pixels to the current 1/11" format based on a 2.2um pixel. As the pixels have shrunk, the lenses for VGA systems have become so small that contamination is now a major issue and the scratch/dig requirements for each lens surface are very tight making the lenses very difficult to manufacture.

3. The Problem of Scale

Fig.2: 3-element lens, disassembled. Barrel, three plastic aspheric lenses, thin sheet aperture stop and baffle.

It is interesting to consider the differences between these miniature camera module lenses and lenses for conventional photography, such as the 35 mm format. The goal is the same: Produce pleasing images of snapshot quality. However, the scale of the optical system is reduced by roughly a factor of ten!

	35 mm point and shoot	35 mm single use	¼" CMOS
Film format diagonals:	43 mm	43 mm	4.4 mm
Lens EFL:	37.5 mm	37.5 mm	3.8 mm
f/number:	2.8, variable	11, fixed	2.8, fixed
Entrance pupil diam:	13.4 mm	3.4 mm	1.36 mm
Spatial frequencies:	10 – 40 /mm	10 – 20 /mm	50 – 100 /mm
Cost:	$10 (est.)	$0.50 (est.)	$1 (est.)

If we were able to simply scale the 35 mm lens design by 1/10x, we would encounter a few issues:

1) Smaller entrance pupil: Depth of field will be much greater, but diffraction will limit performance sooner than with larger formats.
2) Surface figure tolerances: Figure tolerances (fringes of irregularity, for example) will be somewhat tighter, because spatial frequencies of interest are higher, but because the surfaces are smaller, they will be easier to achieve in practice.
3) Geometric tolerances: Scaling the system's size requires linear tolerances to scale as well. So center thickness tolerances and surface and element decenter tolerances will be tighter by a factor of ten. This proves to be the greatest challenge of producing these lenses.
4) Angular tolerances: Lens tilt tolerances do not scale down, but small defects on flanges or mounting surfaces will have a larger effect on tilt.
5) Stray light considerations: An aperture or baffle feature that has an acceptably small dimension at the large scale should be scaled down by 1/10. However, some parts cannot be made thin enough, or they may become translucent, so they will cause a larger fraction of the light to scatter from their edges, resulting in flare or veiling glare.
6) Scratch/Dig and Contamination: The smaller system is much more sensitive to defects and contamination causing shadowing on the image. Acceptable defect dimensions scale with the format size, and the situation is often worse in practice, because the back focal distance is very short and defects close to the image are more visible.

4. Specifications

The following are typical lens specifications for a ¼" sensor format:

FOV	60 degrees
Image Circle	4.6 mm diam.
TTL	5.0mm
f/no	f/2.8
Distortion	<2%
Chief Ray Angle	<22 degrees
Relative Illumination	>50%

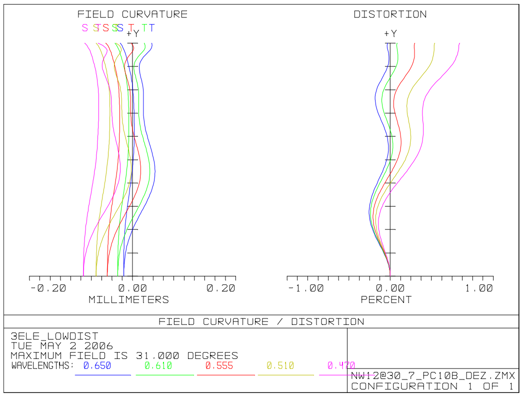
FOV - The field of view for these systems is typically 60 to 66 degrees across the sensor diagonal, but the design must include a slightly larger angle to allow for correction over the image circle.

Image Circle - This is the diameter of the image over which the lens has to be well corrected to allow for lateral displacement of the sensor relative to the optical axis. Lens to sensor centration errors are caused mostly by uncertainty in the placement of the sensor on its circuit board. To allow for those errors, the lens image circle is increased by at least 0.2 mm. As sensors get smaller sensor placement accuracy must improve.

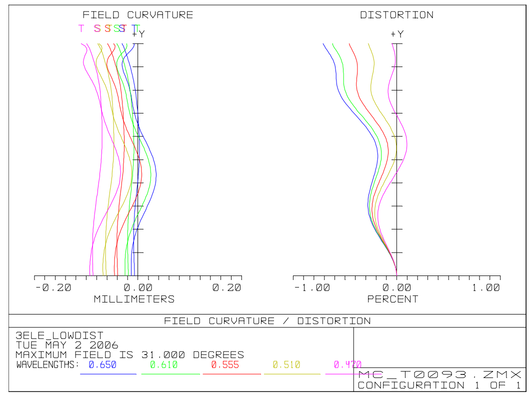
TTL- The total track length is the distance from the front of the barrel to the image plane, this has to be longer than the optical track length by at least 0.050mm in order to protect the front of the lens. This is extremely important to the cell phone designers because of the market pressure to produce thinner phones.

f/number – Although most camera module customers specify f/2.8, it is not uncommon to see lenses at f/3.0 and f/3.3 when the increased fno has a significant effect on performance or manufacturability. However, smaller pixel sensors have less light gathering capability and will suffer at slower f/numbers.

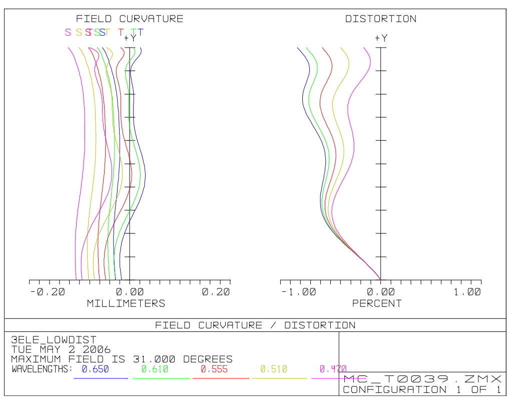
Distortion – The usual distortion requirement is <2% optical distortion or <1% TV distortion. Although this sounds like a much more stringent requirement than the 4% typically allowed in traditional 35mm camera lenses, the distortion curve can vary significantly from assembly to assembly due to build tolerances. In fact the approximate effect of tolerances is to add positive or negative slope to the nominal distortion curve.



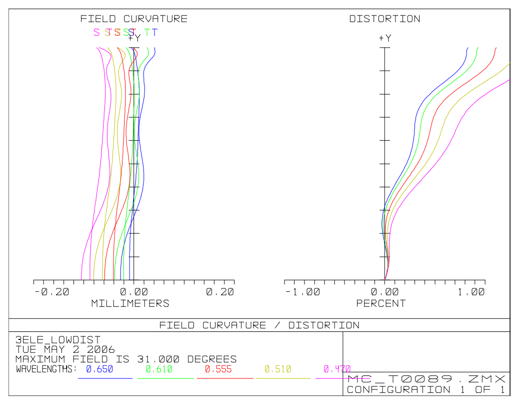
a) Distortion: Nominal Design



b) Distortion: Toleranced Build #1



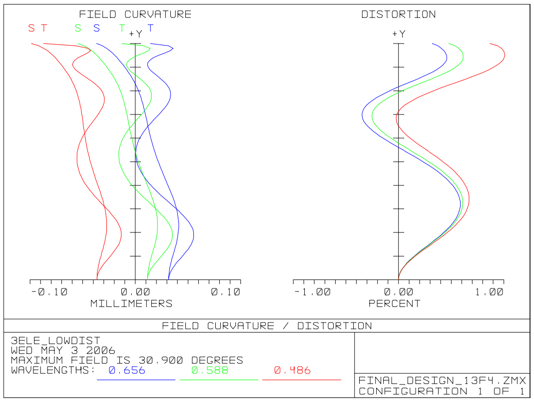
c) Distortion: Toleranced Build #2

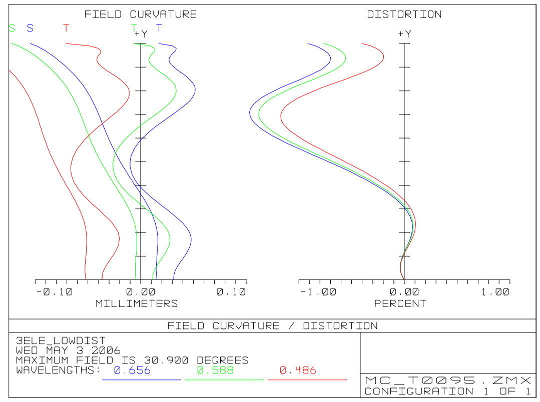


d) Distortion: Toleranced Build #3

Fig.3: a) Nominal design distortion curve, b) Distortion curve for a simulated toleranced build, displaying moderate tilt, c) Another sample of a simulated build with induced tilt in the distortion curve, d) Distortion curve representing the simulated build with the maximum amount of tilt generated for this design.

As demonstrated in fig.3, a nominal design with distortion < 0.3% can easily generate distortion >1% when fabricated. An even more critical factor in ensuring good performance is to limit the slope and rate of change of slope of the distortion curve. The added tilt due to tolerances applied to a fast changing distortion curve can result in extremely steep slopes that are objectionable in an image.





a) Distortion: Nominal Design b) Distortion: Toleranced Build

Fig.4: a) Nominal design distortion is low in magnitude but fast changing over the field, b) Distortion curve for simulated build displaying unacceptable tilt and variation in slope as a result of build tolerances.

Even though absolute distortion values may be low, large changes in slope over a small area will be noticeable in an image. For this reason it is important to control both the shape and the magnitude of the distortion curve.

Chief Ray Angle (CRA)– The CRA is the incidence angle of the chief ray at the image plane for any field point. The CRA is usually specified as a maximum value that cannot be exceeded anywhere in the field. Most camera module lens CRA curves increase monotonically with field to a maximum value and then drop off at the edge of the image, because of pupil aberrations. See fig.5.

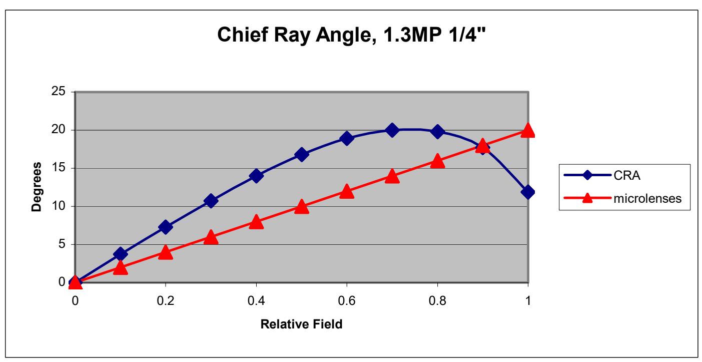


Fig.5: Chief Ray Angle and Microlens Optimum Acceptance Angle as a Function of Relative Field

To better illustrate the source of this requirement, let’s first take a closer look at the structure of the focal plane. The CMOS sensor array is an array of sensors with color filters integrated, to produce the standard Bayer pattern of red, green and blue detectors:

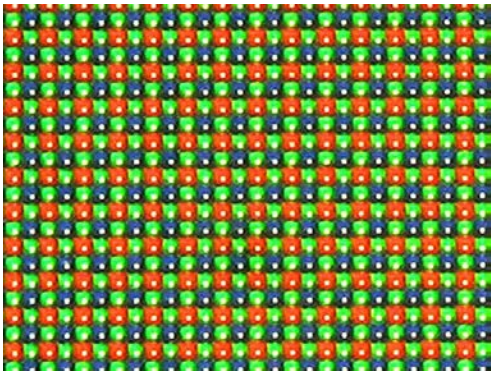


Fig.6: Photomicrograph of a portion of a Bayer pattern sensor. 2.8um pixels.
Note the specular highlights from microlens surfaces.

The surface of the detectors is not uniformly sensitive, though. Circuitry integrated with the sensor reduces the active area significantly. To improve sensitivity, an array of microlenses is applied to the top of the sensor:

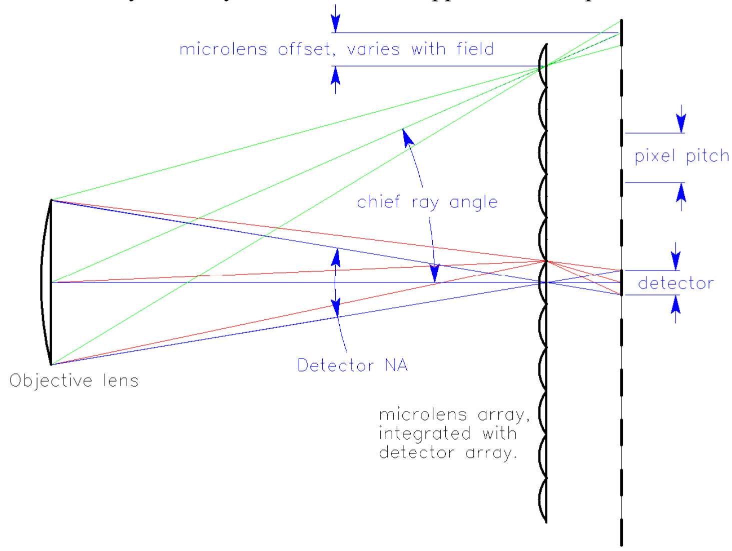


Fig.7: Microlenses located above active area of sensor, are positioned relative to pixel location based on expected incident angle and enhance the sensor's light collecting ability by magnifying the effective area of each pixel. [Highly schematic drawing, not to scale.]

These lenses act as condensors, relaying the sensor image to the exit pupil of the lens. This increases the apparent size of the detectors, improving sensitivity, because the diameter of the microlens becomes the apparent size of the detectors. The plane of microlenses is effectively the image plane of the system. The microlensed detectors now have limited angular response; if the exit pupil of the taking lens is increased beyond the size of the detector image, system sensitivity does NOT increase. In practice, the microlenses are not perfectly formed, so their imaging is crude, but they do improve performance.

The CRA curve illustrated in fig.5 represents a lens designed for a maximum CRA value of 20 degrees. The purpose of the CRA constraint is to maximize the light collection efficiency of the microlenses. Instead of centering each microlens on its pixel, the sensor manufacturers have offset the center of each microlens in order to compensate for the incidence angle of chief rays. Ideally the microlens distribution would exactly match the CRA variation of the lens it was to be used with, but this is not generally seen in practice. Typically the microlens offsets vary linearly with radial position from the center of the sensor, and are designed to minimize CRA/microlens mismatch based on expected lens CRA

curves. The effect of mismatch is a drop in light collection efficiency or decreased relative illumination at the image, or cross-talk between microlenses and adjacent pixels, resulting in false coloration.

Today, maximum CRA specifications for different sensor formats are readily available in the <12 degree to <26 degree range, with the larger CRA allowances corresponding to smaller VGA formats (2.2um, 3.6um). The demand for shorter TTL's is putting pressure on sensor manufacturers to increase their maximum allowable CRA values. Added constraints and fewer elements are lessening the lens designer's ability to deliver good image quality performance and low CRA's.

Relative Illumination – The relative illumination is the level of light energy incident at the image plane for a given field point relative to that at the center of the image.

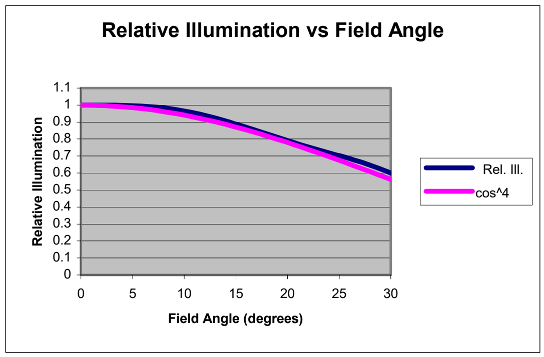


Fig.8: Relative Illumination and Cos^4 as a Function of Field Angle

The blue curve in fig.8 is a typical relative illumination plot. Lens specifications usually require a value greater than 50% at the edge of the field. This corresponds roughly to cos^4, so there is rarely enough corner illumination to allow vignetting for aberration control. If relative illumination meets the requirements, the final image is corrected electronically. Also, it's important that the drop in the relative illumination curve is not precipitous towards full field, or a slight decenter of the sensor relative to the optical axis will cause one corner of an image to appear noticeably dark.

5. Designing

When first beginning a lens design, it is not obvious how many elements to use or which materials. The biggest challenge in designing these systems is to create a lens that is insensitive to tolerances and will perform well when built. Each additional element adds tolerances that will degrade the as-built performance. But each element also adds variables that can be used to increase nominal performance while meeting system and manufacturing constraints.

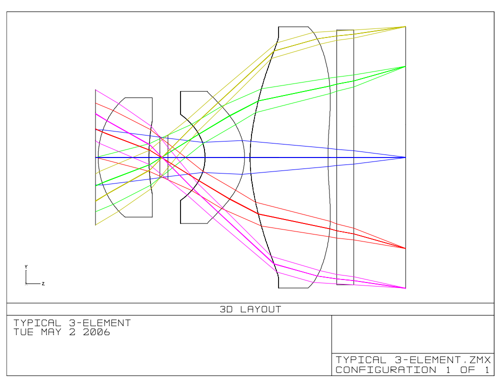


Fig.9: A typical 3-plastic element (3p) imaging system.

The three-element form is very common (fig.9), and a good place to start. Just about every camera module lens manufacturer has a lens of this form in their offerings. Designs tend not to be stop-symmetric. The aperture stop is usually towards the front of the lens, often before the first element, which helps CRA and TTL. The majority of these lenses are all-plastic although some incorporate one glass element (usually the front element) for the advantages of high-index refraction and color correction. Plastic elements are almost always bi-aspheric, and frequently the aspheres are not subtle! The shape of the last lens surface in the design above is typical. Four element systems provide high performance, but are only viable when the TTL is relatively large (>6.0mm), otherwise the performance degradation due to tolerances cancels out the nominal gain. Four element systems are mostly found in cameras with ¼” sensor formats or larger, though they are becoming less common. Likewise, the effectiveness of a 3-element approach decreases to the point that a 2-element system becomes more practical when the TTL is less than 4 mm.

Part of the selection process, when considering materials, is the cost of satisfying the manufacturing constraints. Plastic injection molded optics have minimum edge thicknesses, minimum center thickness and a range of acceptability for their center to edge thickness ratio that must be met in order that they can be molded. Additionally, the maximum slope that can be diamond-turned in mold inserts and measured in either the lens or the mold is around 45 degrees. One big advantage of plastic is that flanges with mechanical details can be molded that eliminate the need for spacers and allow for mechanically driven centering of one element to another. One disadvantage is that there are very few plastic materials that lend themselves to precision optical molding with stability over large ranges of temperature and humidity, so the choices are limited.

Traditional glass lenses have similar types of requirements but with different values, based on their own manufacturing processes. The inability of lens manufacturers to accurately center the outer dimension of these elements on the optical axis, makes precise mounting very difficult. The benefits of traditional glass is reduced as the TTL requirements become shorter.

Another option becoming more readily available is molded glass, allowing the advantages of both high index and aspheric correction. Some current issues with molded glass are the small number of flint-type glasses available for molding, surfaces with inflections can only be used under very limited circumstances and flanges can only be formed in a restricted range of shapes, no sharp corners or abrupt changes in slope are allowed. Cost and manufacturing capacity also limit the use of molded glass elements today. Nevertheless molded glass can be the lens type of choice when the goal is stability over extreme ranges of conditions, or great lengths of time.

6. Performance Requirements

Lens performance for digital sensors is commonly expressed in terms of MTF at spatial frequencies between Nyquist/2 (Ny/2), and Nyquist/4 (Ny/4). The Nyquist frequency is 1/(2*(pixel size)), so for 5.6um pixels Ny/2 is 45 lp/mm and Ny/4 is 22.5 lp/mm; for 1.75 pixels Ny/2 is 143 lp/mm, Ny/4 is 71.4 lp/mm.

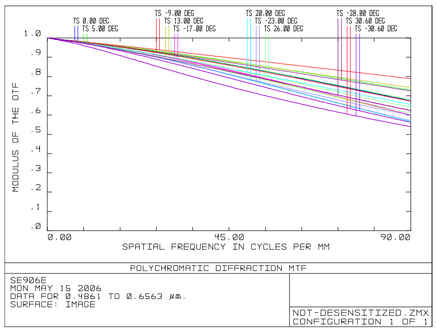
Initially, when pixel sizes were relatively large (5.6um), cell phone manufacturers would specify MTF performance for Ny/2 and even Ny. This was because Ny/2 was still a relatively low frequency, so the requirements were possible to meet. As pixels became smaller (3.6-2.8um), the specifications gravitated to significant response at Ny/4 and Ny/2. These requirements were more challenging, but the size was allowed to grow to help satisfy the MTF requirements. At the same time the tooling capability of manufacturers was increasing so that build tolerances could be decreased, improving performance. The combination of these factors allowed delivery of high performance camera modules. And then the drive to reduce TTL began.

As cell phone manufacturers began demanding smaller and smaller camera modules to be able to offer extremely thin cell phones, image quality became secondary to size. Today most cell phone manufacturers understand that imposing severe size restrictions will significantly compromise image quality, and they are willing to accept worse performance based on Ny/2 and Ny/4 MTF response than with previous camera modules. This means that the image quality of 2MP camera modules are not all alike; as the pixels get smaller the image quality will be worse, and even newer, thinner

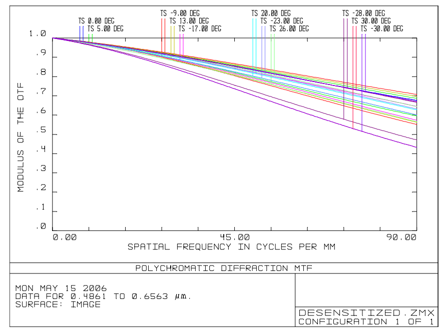
versions of cameras based on the same sensor will have worse performance. The opposing requirements of good image quality and short TTLs coupled with the shrinking size of pixels are rapidly running into the limitations of physics.

7. Tolerance-limited Design

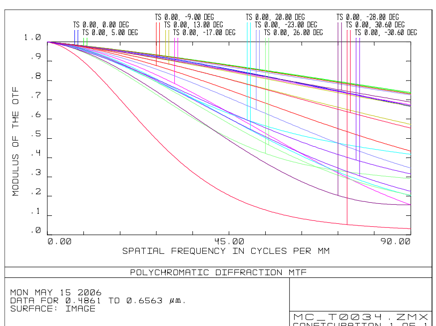
The lens designer must consider manufacturing tolerances at the optimization stage, compromising nominal performance to achieve improved as-built performance. Nevertheless, manufacturing processes are not always available to achieve the necessary tolerances. One of the most challenging aspects of designing lenses for camera modules is desensitizing the system. If sensitivity to manufacturing tolerances is not built into the merit function, then the lens will not be manufacturable.



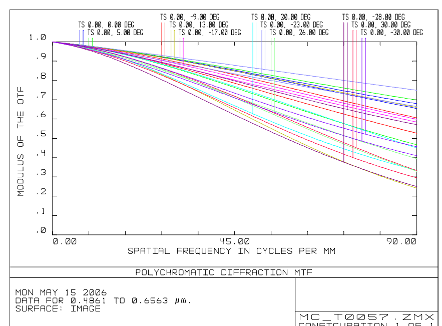
a) Nominal Design - Lens A



b) Nominal Design - Lens B



c) 50th Percentile Build - Lens A



d) 50th Percentile Build - Lens B

Fig.10: a) and b) Nominal MTF curves for two lens designs, lens B has been desensitized to the effects of manufacturing tolerances, lens A has not; c) and d) 50th percentile MTF curves representing a typical manufactured lens, based on simulated builds. The manufacturable MTF performance of lens A is greatly deteriorated from the nominal, the performance of lens B holds up much better when manufacturing tolerances are applied.

Fig.10 illustrates the impact of including desensitization in the optimization process. As the MTF curves clearly illustrate, a desensitized lens generally has slightly lower performance than a lens that has not been desensitized, but the benefit in the performance stability of manufactured systems more than offsets this difference, improving the overall performance of the manufactured lens population.

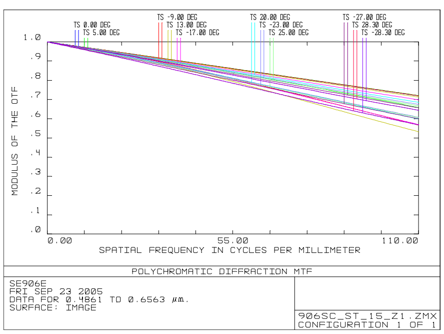
Due to the significant risk that an unfortunate combination of build tolerances will produce a lens with unacceptable performance, most lenses for miniature camera modules are 100% tested for image quality, usually with commercially available test systems that measure through-focus MTF. Performance is judged at representative points across the field, usually at one or two spatial frequencies. Evaluating MTF in two defocused planes can quickly expose field tilt or curvature problems.

The vast majority of systems are built in threaded barrels and focused at assembly, with no other alignments performed. Accurate, tight threads are difficult to produce, and they present measurement and contamination problems. Alternatives that allow alignments for lens to sensor centration and tilt are being implemented. As pixel counts get higher and sensor dimensions get smaller, these alignments are becoming more critical.

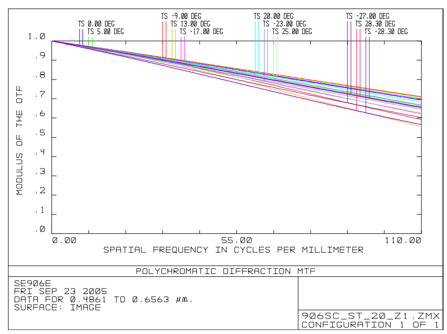
The problem of communication of quality between lens manufacturers and their customers is important. Manufacturers usually produce their own designs, and they are unwilling to share design data with customers. Also, actual manufacturing tolerance capability is not usually available, so it is not possible to verify the manufacturability of a new design. Standard methods of predicting production quality are needed to avoid unpleasant surprises during volume manufacturing.

8. TTL and Desensitization

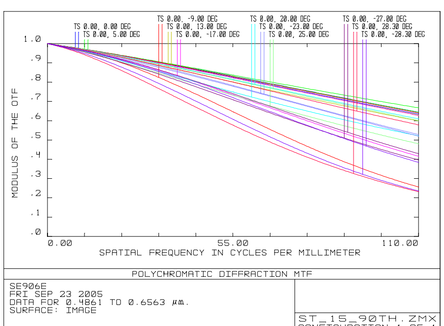
The ability of the designer to desensitize a lens is directly tied to the TTL and, for shorter forms, the BFL constraints. For instance, the 2MP 2.8um sensor required a lens with good performance over a large format. We were able to produce a lens that consistently delivers good image quality only because the TTL for this system was allowed to increase to as large as 7.8mm. The longer the TTL, the more modest the refraction needed at each surface, the weaker each lens can be and the less sensitive the performance of the system is to build tolerances. The more constrained the lens system in length, the more refractive power is needed at each surface, and the more sensitive the lens becomes to tolerance-induced image degradation.



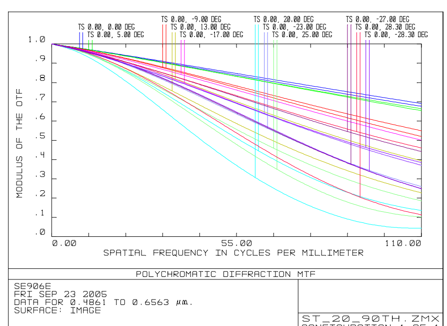
a) Nominal Design - Lens A (TTL=7.5 mm)



b) Nominal Design - Lens B (TTL=6.5 mm)



c) 90^{th} Percentile Build - Lens A (TTL=7.5 mm)



d) 90^{th} Percentile Build - Lens B (TTL=6.5 mm)

Fig.11: a) and b) Nominal MTF curves for two 4-element lens designs constrained by different TTLs, the performance is essentially identical; c) and d) MTF curves representing 90^{th} percentile performance based on simulated builds. The longer TTL results in more consistently high performance.

The MTF curves in fig.11 illustrate the effect of TTL on desensitization. The additional constraint of conforming to a shorter TTL increases the difficulty of designing a manufacturable lens with acceptable performance and reasonable yields. Although this exercise was performed using a relatively long TTL lens (an older design), the same concept applies to today's shorter TTL designs for systems with three elements or more.

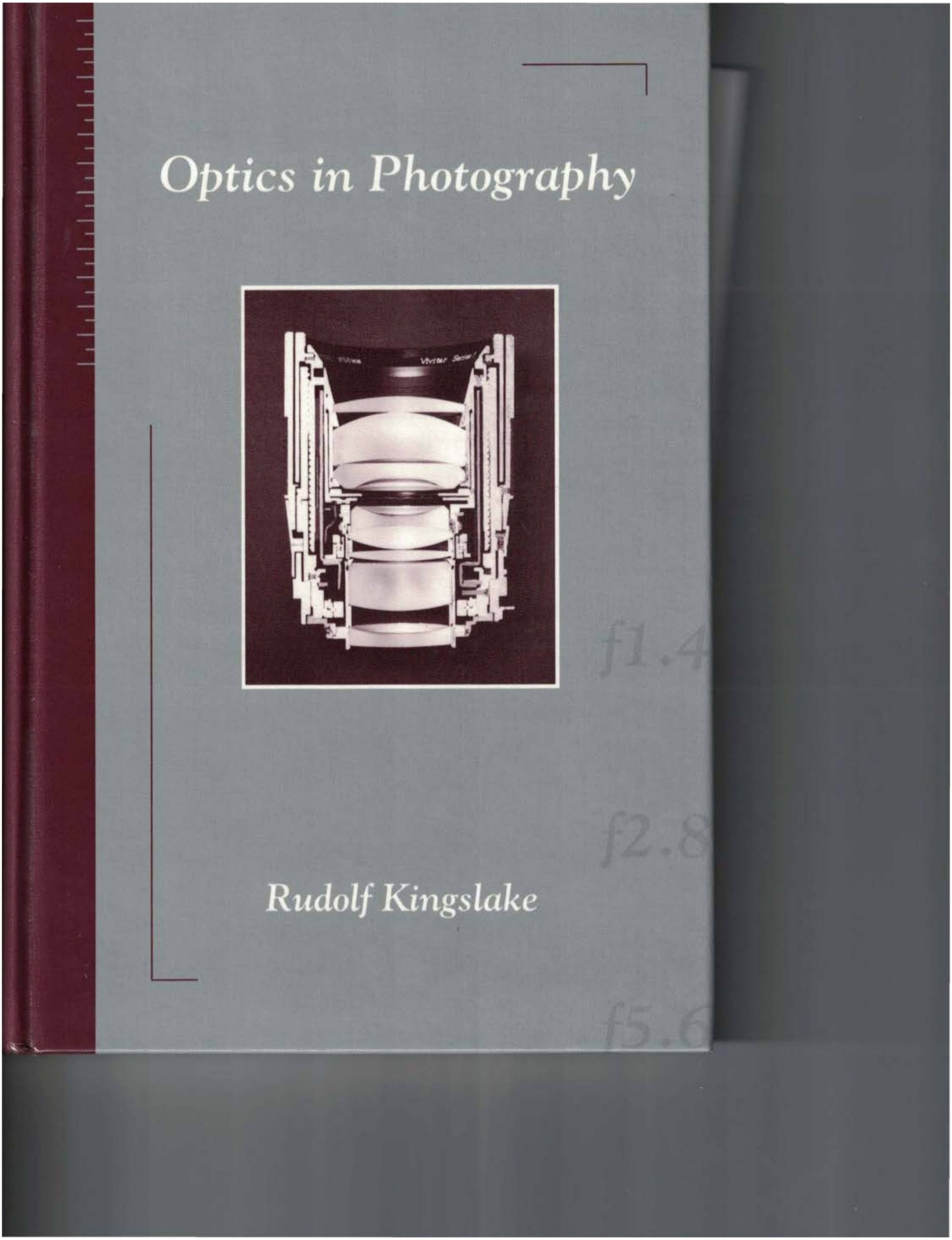
Two-element systems often naturally adopt forms with short TTL's, but desensitization to tolerances can require a relatively short BFL. Positioning the IR filter in such a system can be challenging. It is important for the back surface of the filter to be as far as possible from the sensor to ensure small surface defects and contamination are adequately out of focus. The closer to the sensor, the more restrictive the acceptability requirements on defect size. An IR filter positioned too close to the sensor could require such a tight scratch dig specification as to make it prohibitively costly or unmanufacturable.

The primary focus in recent camera module development has shifted from image quality to size and lens designers are being pressured to design lenses with shorter and shorter TTLs. Recent lenses for ¼" formats are being held to TTLs<5.0mm and there are plans for new lenses for the same format to be even shorter. Of course the pixels are smaller, so Ny/2 is higher (113.6 lp/mmfor 2.2um pixels, 142.9 lp/mm for 1.75um pixels) making the problem even more difficult.

9. Future Prospects

We believe that the race for smaller pixels is slowing, because Moore's law cannot shorten the wavelength of visible light, or increase the brightness of photographic subjects. Pixels whose dimensions are under 2 um have limited light-collection ability, and much faster f/number lenses are unlikely to be developed. The continuing pressure to design with very short TTL's both for packaging and cost considerations suggests that in the near term the customer can expect worse image quality from camera modules using sensors with these very small pixels. Perhaps the market will split, to allow a choice between low cost/very small/modest quality cameras, and more costly/larger cameras that can rival today's digital still cameras.

The path to sharpness improvement most likely involves a hybrid solution incorporating a desensitized lens design combined with improved build tolerances, active alignment at lens and camera assembly, image processing for improved depth of field, or all three. There are companies currently developing image processing methods to improve image quality and depth of field in digital images. These methods may allow us to build simplified, desensitized lens systems whose performance is corrected by digital image processing. There are, of course, tradeoffs to be made between sharpness, noise levels and electronic complexity. In each case there will be added costs; it will interesting to see what cost/image quality balance cell phone manufacturers finally select to offer their customers in the next generation of cell phone cameras products.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The Brightness of Images

The relation between the aperture of a lens and the brightness of the image produced by it on the photographic emulsion is often misunderstood, yet it is of the greatest importance to the photographer who wishes to make the best use of the equipment. The tremendous efforts of lens designers and manufacturers that have been devoted to the production of lenses of extremely high relative aperture are an indication of the need that exists for brighter images and "faster" lenses.

In this chapter, we are concerned with the flow of light from an object, through a lens, to the image. Several photometric terms must be understood before we can give a precise statement of this effect, and of the factors that control the brightness of the image projected on the film in a camera.

The *illumination* (illuminance) produced by a lamp at any distance from it is found by dividing the candle power of the lamp by the square of the distance (the inverse square law). Thus, a 50-candle lamp will produce, at a distance of 3 feet, an illumination of $50/9 = 5.6$ foot-candles. The illumination in a well-lighted factory or classroom may reach 50 foot-candles, and in motion-picture or television studios, illuminations as high as 200 to 300 foot-candles are common.

The term *flux* is used to express a quantity of light. The unit of flux is the lumen, defined as the amount of light falling on each square foot of a surface under an illumination of 1 foot-candle; hence, foot-candles and lumens per square foot are two ways of expressing the same thing. The convenience of this term may be seen by an example. Suppose we know that a certain 16mm projector emits 550 lumens. Then, if the projected image is 3×4 ft, the average illumination on the screen will be $550/12 = 46$ foot-candles; if the image is 5×6.6 ft, the illumination will be $550/(5 \times 6.6) = 16.7$ foot-candles, and so on.

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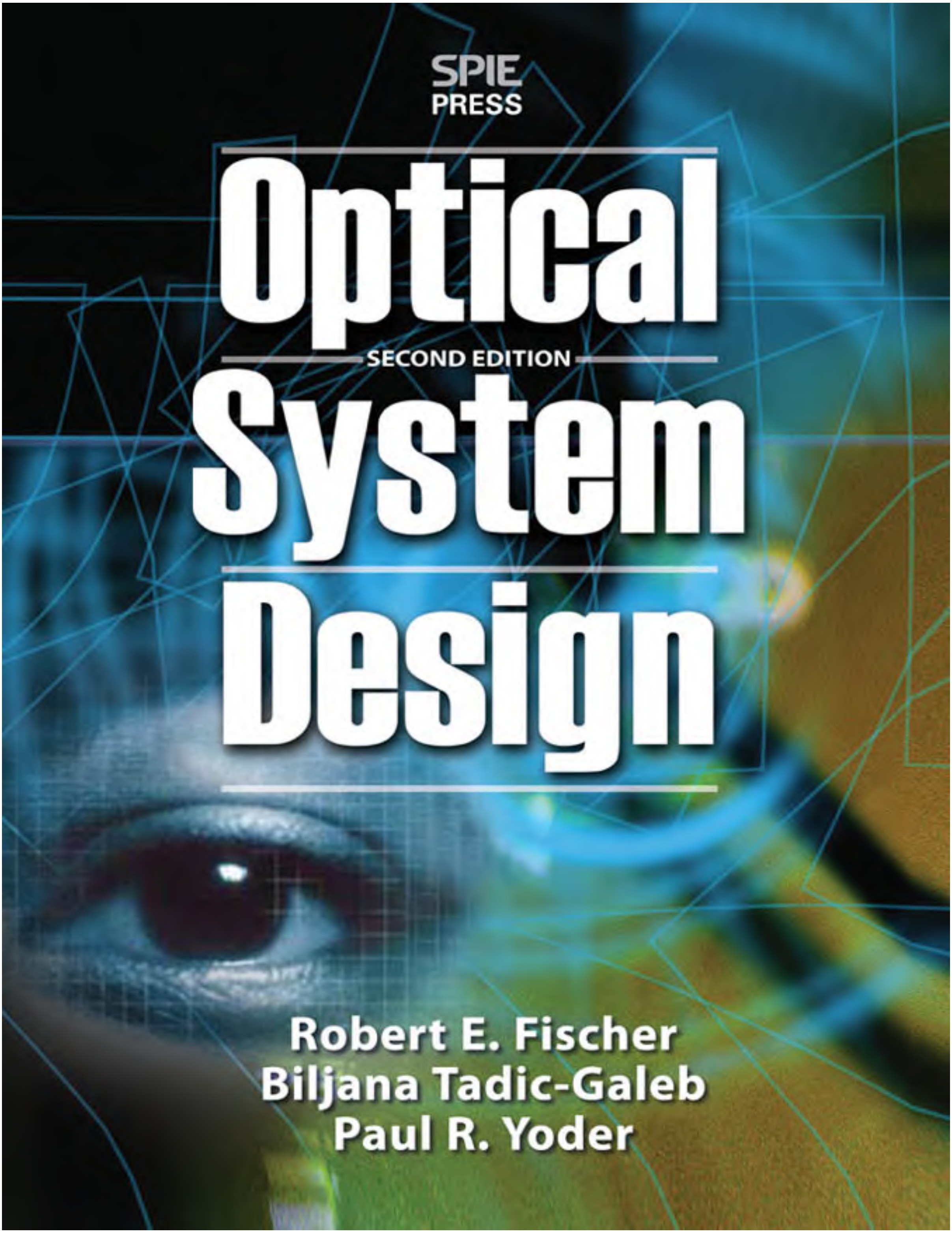
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OPTICAL SYSTEM DESIGN

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CHAPTER 9

The Optical Design Process

The optical design process includes a myriad of tasks that the designer must perform and consider in the process of optimizing the performance of an imaging optical system. While we often think primarily of the robustness of the optimization algorithm, reduction of aberrations, and the like, there is much more to do. The designer must be at what we sometimes call "mental and technical equilibrium with the task at hand." This means that he or she needs to be fully confident that all of the following are understood and under control:

- All first-order parameters and specifications such as magnification, focal length, *f*/number, full field of view, spectral band and relative weightings, and others.
- Assure that the optical performance is being met, including image quality, distortion, vignetting, and others.
- Assure that the packaging and other physical requirements, including the thermal environment, is being taken into account.
- Assure that the design is manufacturable at a reasonable cost based on a fabrication, assembly, and alignment tolerance analysis and performance error budget.
- Consider all possible problems such as polarization effects, including birefringence, coating feasibility, ghost images and stray light, and any other possible problems.

Once every one of these items has been addressed and is at least recognized and understood, we start with the sketch of the system. First, the system is divided into subsystems if possible, and the first-order parameters are determined for each subsystem. For example, if we are to design a telescope with a given magnification, the entrance pupil diameter should be chosen such that the exit pupil size matches the eye pupil. A focal length of the objective and the eyepiece should be chosen such that the eyepiece can have a sufficiently large eye relief. Now, when the specs for each subsystem are defined, it is time to use the computer-aided design algorithms and associated software to optimize the system, which will be discussed in the rest of this chapter. Each subsystem can be designed and optimized individually, and the modules joined together or, more often, some subsystems are optimized separately and some as an integral part of the whole system.

What Do We Do When We Optimize a Lens System?

Present-day computer hardware and software have significantly changed the process of lens design. A simple lens with several elements has nearly an infinite number of possible solutions. Each surface can take on an infinite number of specific radii, ranging from steeply curved concave, through flat, and on to steeply curved convex. There are a near infinite number of possible design permutations for even the simplest lenses. How does one optimize the performance with so many possible permutations? Computers have made what was once a tedious and time-consuming task at least manageable.

The essence of most lens design computer programs is as follows:

- First, the designer has to enter in the program the starting optical system. Then, each variable is changed a small amount, called an *increment,* and the effect to performance is then computed. For example, the first thickness may be changed by 0.05 mm as its increment. Once this increment in thickness is made, the overall performance, including image quality as well as physical constraints, are computed. The results are stored, and the second thickness is now changed by 0.05 mm and so on for all variables that the user has designated. Variables include radii, airspaces,

element thicknesses, glass refractive index, and Abbe number. If you are using aspheric or diffractive surfaces, then the appropriate coefficients are also variables.

- The measure of performance as used here is a quantitative characterization of the optical performance combined with a measure of how well the system meets its first-order constraints set by the user such as focal length, packaging constraints, center and edge thickness violations, and others. The result of the computation is a single number called an *error function* or *merit function*. The lower the number, the better the performance. One typical error function criteria is the rms blur radius, which, in effect, is the radius of a circle containing 68% of the energy. Other criteria include optical path difference, and even MTF, as described in Chap. 15.
- The result is a series of derivatives relating the change in performance (P) versus the change in the first variable (V_1), the change in performance (P) versus the change in the second variable (V_2), and so on. This takes on the following form:

$$\frac{\partial P}{\partial V_1}, \frac{\partial P}{\partial V_2}, \frac{\partial P}{\partial V_3}, \frac{\partial P}{\partial V_4} \cdots$$

- This set of partial derivatives tells in which direction each parameter has to change to reduce the value of the sum of the squares of the performance residuals. This process of simultaneous parameter changes is repeated until an optimum solution is reached.

A lens system consists of a nearly infinite number of possible solutions in a highly multidimensional space, and it is the job of the designer to determine the optimum solution.

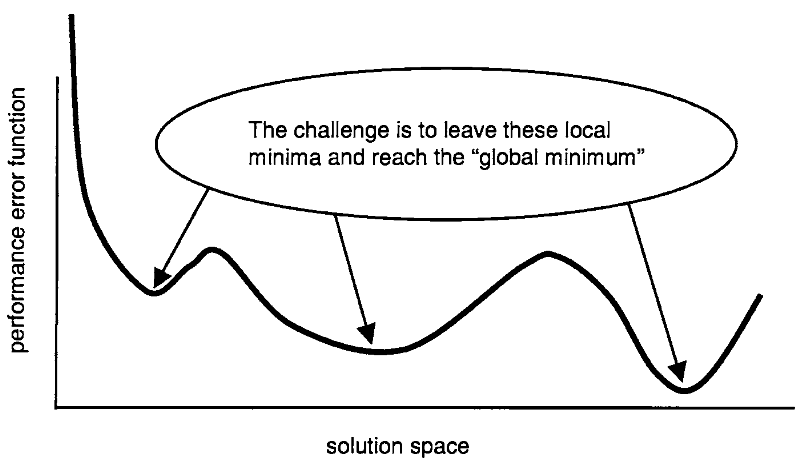
Designers have used the following analogy to describe just how a lens design program works:

- Assume that you cannot see and you are placed in a three-dimensional terrain with randomly changing hills and valleys. Your goal is to locate the lowest elevation or altitude, which in our analogy equates to the lowest error function or merit function. The lower the error function, the better the image quality, with the "goodness" of performance being inversely proportional to the elevation.
- You are given a stick about 2 m long, and you first stand in place and turn around tapping the stick on the ground trying to find which direction to walk so as to go down in elevation.

- Once you determine the azimuth resulting in the greatest drop in elevation, you step forward in that direction by 2 m.
- You now repeat this process until in every direction the elevation goes up or is level, in which case you have located the lowest elevation.
- But what if just over a nearby hill is an even lower valley than you are now in? How can you find this region of solution? You could use a longer stick, or you could step forward a distance several times as long as the length of your stick. If you knew that the derivative or slope downward is linear or at least will continue to proceed downward, this may be a viable approach. This is clearly a nontrivial mathematical problem for which many complex and innovative algorithms have been derived over the years. But the problem is so nontrivial as well as nonlinear that software algorithms to locate the so-called global minimum in the error function are still elusive. Needless to say, the true global minimum in the error function may be quite different or distant from the current location in our *n*-dimensional terrain.

Figure 9.1 shows a two-dimensional representation of solution space as discussed previously. The *ordinate* is the error function or merit function, which is a measure of image quality, and the *abscissa* is, in effect, solution space. We may initiate a design on the left and the initial

Figure 9.1
Illustration of Solution Space in Lens Design



optimization brings the error function to the first minimum called a *local minimum* in the error function. We then change glasses and/or make other changes to the design and ultimately are able to move the design to the next lower local minimum. Finally, we add additional elements and make other changes and we may be able to reach the local minimum on the right. But how do we know that we are at, or even close to, a global minimum? Here lies the challenge as well as the excitement of lens design!

It is important here to note that reaching global minimum in the error function is not necessarily the end goal for a design. Factors including tolerance sensitivity, packaging, viability of materials, number of elements, and many other factors influence the overall assessment or "goodness" of a design. Learning how to optimize a lens system is, of course, quite critical to the overall effort, and learning how to reach a viable local or near-global minimum in the error function is very important to the overall success of a project.

How Does the Designer Approach the Optical Design Task?

The following are the basic steps generally followed by an experienced optical designer in performing a given design task. Needless to say, due to the inherent complexity of optical design, the processes often become far more involved and time consuming. Figure 9.2 outlines these basic steps:

1. The first step in the design process is to *acquire and review all of the specifications.* This includes all optical specifications including focal length, f/number, full field of view, packaging constraints, performance goal, environmental requirements, and others.
2. Then we *select a representative viable starting point.* The starting point should, wherever possible, be a configuration which is inherently capable of meeting the specifications for the design. For example, if the specifications are for an f/10 monochromatic lens covering a very small field of view and having an entrance pupil diameter of 5 mm, then the lens may very well be a single element. However, if the requirements call for an f/1.2 lens over a wide spectral band covering a 40° full field of view, then the solution may very well

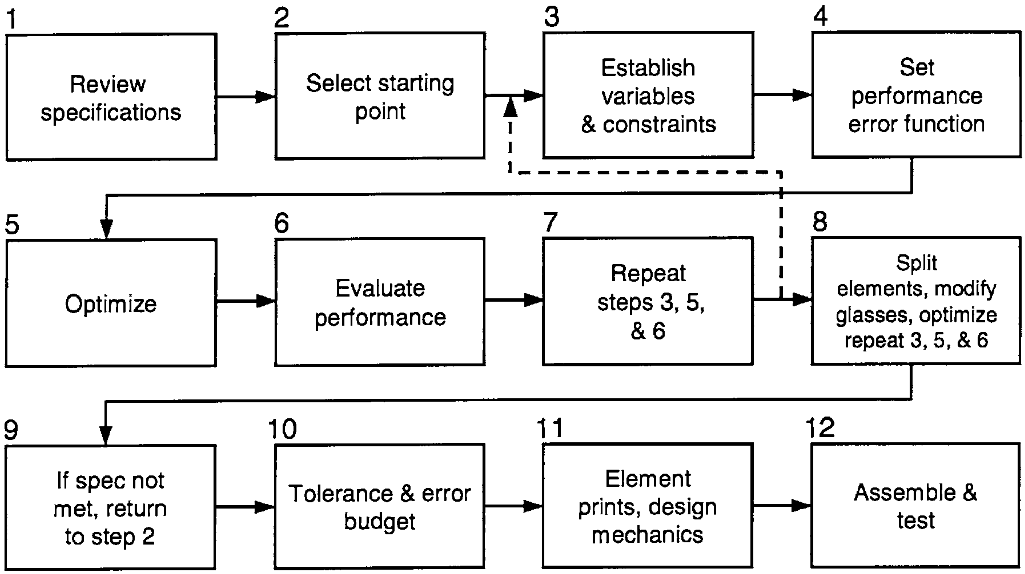


Figure 9.2
Lens Design and Optimization Procedure

be a very complex six- to seven-element double Gauss lens form. If we were to use a single element for this latter starting point, there would be no hope for a viable solution. Finding a good starting point is very important in obtaining a viable solution. The following are viable sources for starting points:

You can use a *patent* as a starting point. There are many sources for lens patents including Warren Smith's excellent book *Modern Lens Design*. There is also a CD-ROM called "LensView," which contains over 20,000 designs from patents. These are all searchable by a host of key parameters. While the authors of this book are not patent attorneys, we can say with confidence that you may legally enter design data from a patent into your computer and work with it in any way that you would like to. If your resulting design is sold on the market, and if the design infringes on the patent you used (or any other for that matter), you could be cited for patent infringement. It is interesting to note that the purpose

of our patent system in this country is to promote inventions and innovation. This is done by offering an inventor a 17-year exclusive right to his or her invention in exchange for *teaching* in the patent how to implement the invention. Thus, you are, in effect, invited to use the design data and work with it with the goal of coming up with a better design, which you can then go out and patent. By this philosophy, inventors are constantly challenged to improve upon an invention, which, in effect, advances technology, which is what the patent process is all about. Needless to say, we urge you to be careful in your use of patents.

You could use a so-called hybrid design. We mean a hybrid to be the combining of two or more otherwise viable design approaches so as to yield a new system configuration. For example, a moderate field-of-view Tessar lens design form can be combined with one or more strongly negatively powered elements in the front to create an extremely wide-angle lens. In effect, the Tessar is now used over a field of view similar to its designed field, and the negative element or elements bend or “horse” the rays around to cover the wider field of view. An *original design* can, of course, be a viable starting point. As your experience continues to mature, you will eventually become comfortable with “starting from scratch.” With today’s computer-aided design software, this works most of the time with simple systems such as doublets and triplets; however, with more complex systems, you may have problems and will likely be better off resorting to a patent or other source for a starting point.

3. Once you have entered your starting point into the software package you are using, it is time to *establish the variables and constraints.* The system variables include the following: radii, thicknesses, airspaces, surface tilts and decenters, glass characteristics (refractive index and Abbe number), and aspheric and/or other surface variables, including aspheric coefficients. The constraints include items such as focal length, f/number, packaging-related parameters (length, diameter, etc.), specific airspaces, specific ray angles, and virtually any other system requirement. Wavelength and field weights are also required to be input. It is important to note that it is not imperative (nor is it advisable) to vary every conceivable variable in a lens, especially early in the design phase. For example, your initial design optimization should

probably be done using the glasses from the starting point, in other words do not vary glass characteristics initially. This will come later once the design begins to take shape and becomes viable. You may also want to restrict the radii or thicknesses you vary as well, at least initially. For example, if adjacent elements have a very small airspace in the starting design, this may be for a good reason, and you should probably leave them fixed. Also, element thicknesses are very often not of great value as variables, at least initially, in a design task, so it is usually best to keep element thicknesses set to values which will be viable for the manufacturer.

4. You now will *set the performance error function and enter the constraints*. Most programs allow the user to define a fully "canned" or automatically generated error function, which, as discussed earlier, may be the rms blur radius weighted over the input wavelengths and the fields of view. In the Zemax program the user selects the number of rings and arms for which rays will be traced into the entrance pupil (rays are traced at the respective intersection points of the designated number of rings and arms). Chapter 22 shows a detailed example of how we work with the error function.

5. It is now time to *initiate the optimization*. The optimization will run anywhere from a few seconds for simple systems to many hours, depending on just how complex your system is and how many rays, fields of view, wavelengths, and other criteria are in the system. Today, a state-of-the-art PC optimizing a six- to seven-element double Gauss lens with five fields of view will take in the order of 5 to 10 s per optimization cycle. Once the computer has done as much as it can and reaches a local minimum in the error function, it stops and you are automatically exited from the optimization routine.

6. You now *evaluate the performance* using whatever criteria were specified for the lens. This may include MTF, encircled energy, rms spot radius, distortion, and others.

7. You now *repeat steps 3 and 5 until the desired performance is met*. Step 3 was to establish the variables and constraints, and step 5 was to run the optimization, and these steps are repeated as many times as necessary to meet the performance goals. You will often reach a solution that simply does not meet your performance requirements. This is very common during the design evolution, so do not be surprised, depressed, or embarrassed if it happens

to you… it happens to the best of us. When it does happen, you may need to *add or split the optical power of one or more of the lens elements* and/or to *modify glass characteristics.* As we have discussed previously, splitting optical power is extremely valuable in minimizing the aberrations of a lens.

8. There is a really simple way of splitting an element in two, and while it is not "technically robust," it does work most of the time. What you do is insert two surfaces in the middle of the current element, the first of which will be air and the second is the material of your initial element. The thickness of each "new" element is one-half of the initial element and the airspace should be small, like 0.1, for example. Now simply enter twice the radius of the original element for both *s*1 and *s*2 of the new elements. You will end up with two elements whose net power sum is nearly the same as your initial element. You can now proceed and vary their radii, the airspace, and, as required, the thicknesses.

9. If you still cannot reach a viable design, then at this point you will need to *return to step 2 and select a new starting point.*

10. Your final task in the design process is to *perform a tolerance analysis and performance error budget.* We will be discussing tolerancing in more depth in Chap. 16. In reality, you should be monitoring your tolerance sensitivities throughout the design process so that if the tolerances appear too tight, you can take action early in the design phase and perhaps select a less sensitive design form.

11. Finally, you will need to *generate optical element prints, contact a viable lens manufacturer, and have your elements produced.* You will also need to work with a qualified mechanical designer who will *design the cell or housing* as well as any required interfaces. It is important to note that while we list the mechanical design as taking place at this point after the lens design is complete, it is extremely important to work with your mechanical designer throughout the lens design process so as to reach an optimum for both the optics as well as the mechanics. Similarly, you should establish a dialog with the optical shop prior to completing the design so as to have time to modify parameters which the shop feels needs attention such as element thicknesses, glass types, and other parameters.

12. Once the components are in house, you will need to *have the lens assembled and tested.* Assembly should be done to a level of precision and cleanliness commensurate with the overall

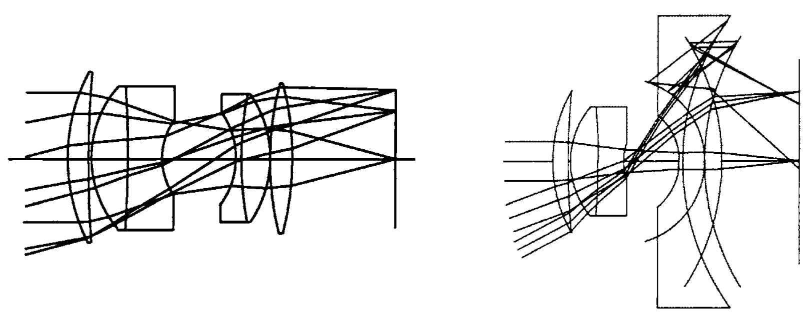
performance goals. Similarly, testing should be to a criterion which matches or can be correlated with your system specifications and requirements. We discuss testing in Chap. 15.

Sample Lens Design Problem

There was a very interesting sample lens design problem presented at the 1980 International Lens Design Conference. The optimized design for an $f/2.0$, 100-mm focal length, 30° full field-of-view double Gauss lens similar to a 35-mm camera lens was sent out to the lens design community. One of the tasks was to redesign the lens to be $f/5$ covering a 55° full field with 50% vignetting permitted. Figure 9.3 shows the original starting design, as well as the design after changing the f/number and field of view, without any optimization.

Sixteen designers submitted their results, and they spent from 2 to 80 h working on the problem. We will present here three representative solutions in Fig. 9.4. The design in Fig. 9.4*a* is what we often call *a happy lens.* What we mean is that the lens is quite well behaved with no steep bending or severe angles of incidence. The rays seem to "meander" nicely through the lens. It is a comfortable design. We show to the right of the layout a plot of the MTF. MTF will be discussed in detail in Chap. 10. For the purpose of this discussion, consider the MTF to be contrast plotted in the ordinate as a function of the number of line pairs per millimeter

Figure 9.3 Starting Design for Sample Lens Design Problem



(a) (b)

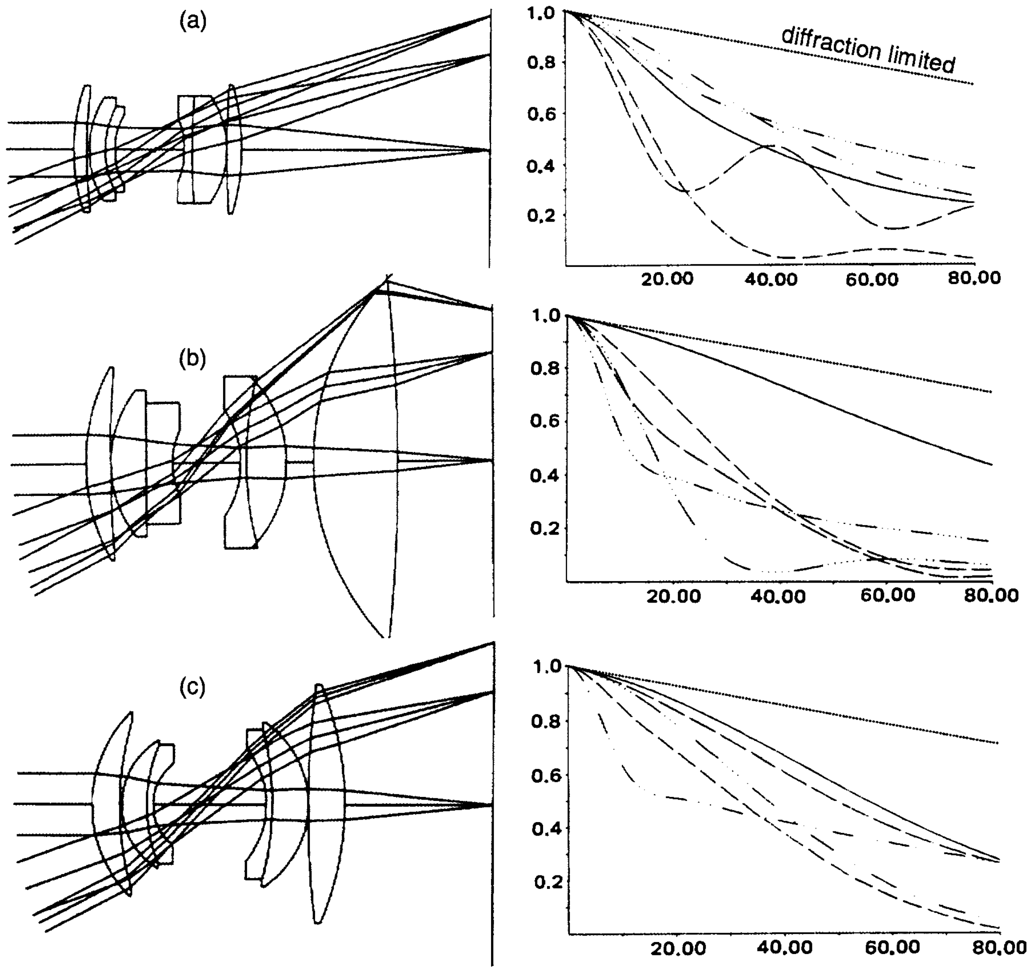


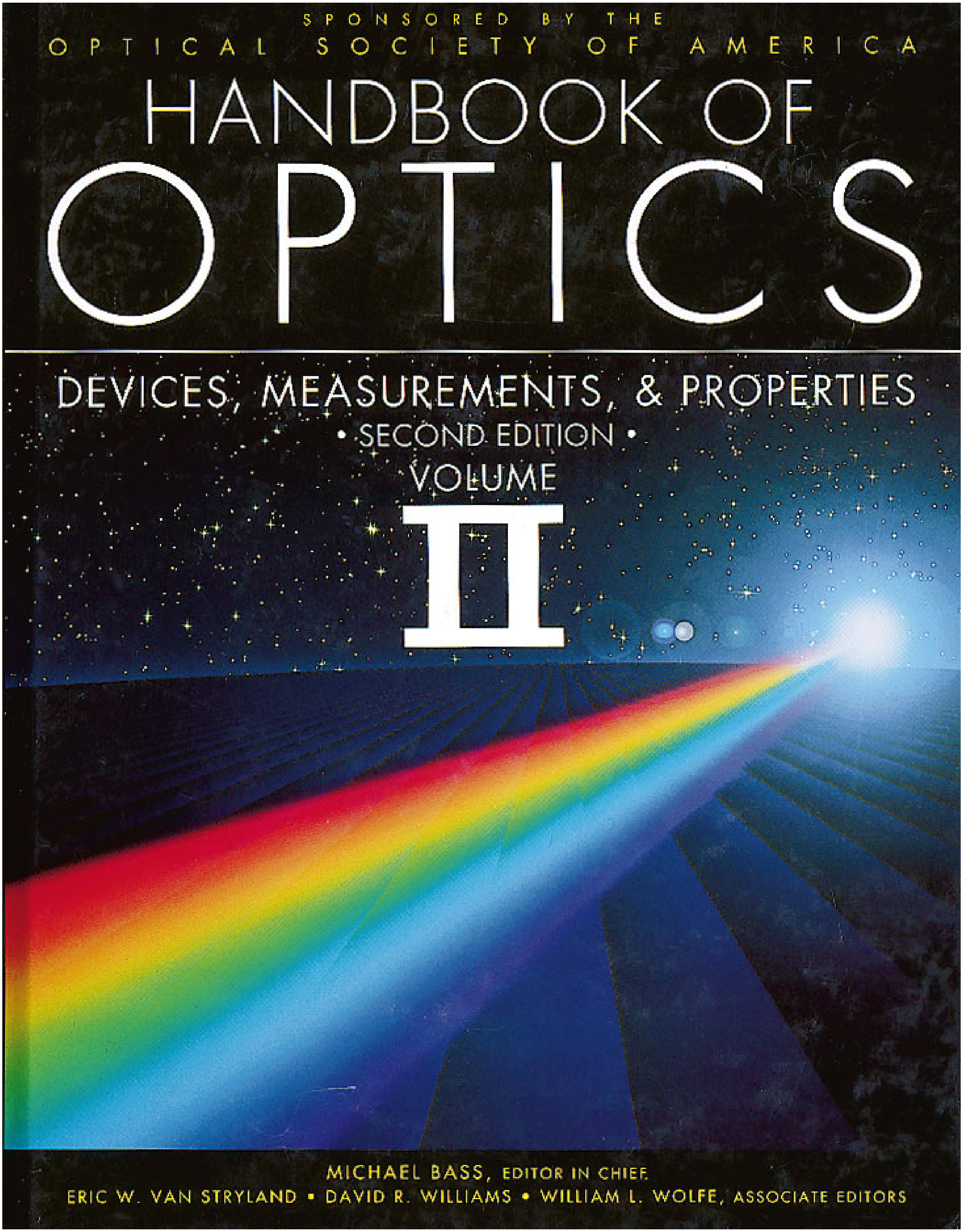
Figure 9.4
Representative Solutions to Sample Lens Design Problem

in the abscissa. The different curves represent different positions in the field of view and different orientations of the resolution patterns. The higher the curves, the better the contrast and the overall performance. The MTF is reasonable for most of the field positions. As will be discussed in Chap. 22, a good rule of thumb for the MTF of a 35-mm camera lens is an MTF of 0.3 at 50 line pairs/mm and 0.5 at 30 line pairs/mm.

The design in Fig. 9.4*b* has a serious problem; the rays entering the last element are at near-grazing angles of incidence. Notice that the exit pupil at full field is to the right of the lens (since the ray cone is descending toward the axis to the right), and at 70% of the field the exit pupil is to the left of the lens (since the ray cone is ascending to the right and therefore appears to have crossed the axis to the left of the lens). This is a direct result of the steep angles of incidence of rays entering the last element. The variation in exit pupil location described here would not itself be an issue unless this lens were used in conjunction with another optical system following it to the right; however, it does indicate clearly the presence of the severe ray bending which will inevitably lead to tight manufacturing and assembly tolerances. Further, the last element has a near-zero edge thickness which would need to be increased. The lens is large, bulky, and heavy. And finally, the MTF of this design is the lowest of the three designs presented.

Finally, the design in Fig. 9.4*c* is somewhat of a compromise of the two prior designs in that it is somewhat spread out from the design in Fig. 9.4*a* but does not have the problems of the design in Fig. 9.4*b*. The MTF of the design in Fig. 9.4*c* is the best of the three designs.

Comparing the three designs is very instructive as it shows the extreme variability of results to the same problem by three designers. The question to ask yourself is what would you do if you subcontracted the design for such a lens, and after a week or two the designer brought you a stack of paper 200-mm thick with the results of the design in Fig. 9.4*b*. And what if he or she said "wow, what a difficult design! But I have this fabulous solution for you!" Prior to reading this book, you might have been inclined to congratulate the designer on a job well done, only to have problems later on during manufacturing and assembly. Now, however, you know that there may be alternate solutions offering superior performance with looser tolerances and improved packaging. Remember that even a simple lens has a near infinite number of possible solutions in a multidimensional space.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1.5 F-NUMBER AND NUMERICAL APERTURE

The focal ratio or F-number (FN) of a lens is defined as the effective focal length divided by the entrance pupil diameter D_{ep}. When the object is not located at infinity, the effective FN is given by

$$\mathrm{FN}_{eff} = \mathrm{FN}_{\infty}(1 - m) \tag{12}$$

where m is the magnification. For example, for a simple positive lens being used at unity magnification ($m = -1$), the $\mathrm{FN}_{eff} = 2\mathrm{FN}_{\infty}$. The *numerical aperture* of a lens is defined as

$$\mathrm{NA} = n_i \sin U_i \tag{13}$$

where n_i is the refractive index in which the image lies and U_i is the slope angle of the marginal ray exiting the lens. If the lens is aplanatic, then

$$\mathrm{FN}_{eff} = \frac{1}{2\mathrm{NA}} \tag{14}$$

1.6 MAGNIFIER OR EYE LOUPE

The typical magnifying glass, or *loupe,* comprises a singlet lens and is used to produce an erect but virtual magnified image of an object. The magnifying power of the loupe is stated to be the ratio of the angular size of the image when viewed through the magnifier to the angular size without the magnifier. By using the thin-lens model of the human eye, the magnifying power (MP) can be shown to be given by

$$\mathrm{MP} = \frac{25 \text{ cm}}{d_e + d_o - \phi d_e d_o} \tag{15}$$

where d_o is the distance from the object to the loupe, d_e is the separation of the loupe from the eye, and $\phi = 1/f$ is the power of the magnifier. When d_o is set to the focal length of the lens, the virtual image is placed at infinity and the magnifying power reduces to

$$\mathrm{MP} = \frac{25 \text{ cm}}{f} \tag{16}$$

Should the virtual image be located at the near viewing distance of the eye (about 25 cm), then

$$\mathrm{MP} = \frac{25 \text{ cm}}{f} + 1 \tag{17}$$

Typically simple magnifiers are difficult to make with magnifying powers greater than about 10×.

1.7 COMPOUND MICROSCOPES

For magnifying power greater than that of a simple magnifier, a compound microscope, which comprises an objective lens and an eyepiece, may be used. The objective forms an aerial image of the object at a distance s_{ot} from the rear focal point of the objective. The

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(12) **United States Patent**
Chen et al.

(10) **Patent No.: US 10,324,273 B2**
(45) **Date of Patent: Jun. 18, 2019**

(54) **OPTICAL LENS SET**

(71) Applicant: **Genius Electronic Optical Co., Ltd.**, Taichung (TW)

(72) Inventors: **Feng Chen**, Fujian (CN); **Baina Chen**, Fujian (CN); **Yanxuan Yin**, Fujian (CN)

(73) Assignee: **Genius Electronic Optical (Xiamen) Co., Ltd.**, Xiamen, Fujian (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 127 days.

(21) Appl. No.: **15/286,575**

(22) Filed: **Oct. 6, 2016**

(65) **Prior Publication Data**

US 2018/0059371 A1 Mar. 1, 2018

(30) **Foreign Application Priority Data**

Aug. 29, 2016 (CN) 2016 1 0755720

(51) **Int. Cl.**

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G02B 13/00	(2006.01)
G02B 5/00	(2006.01)
G02B 5/20	(2006.01)
G02B 27/00	(2006.01)

(52) **U.S. Cl.**

CPC ***G02B 13/0045*** (2013.01); *G02B 5/005* (2013.01); *G02B 5/20* (2013.01); *G02B 9/60* (2013.01); *G02B 27/0025* (2013.01)

(58) **Field of Classification Search**

CPC .. G02B 13/02; G02B 13/009; G02B 13/0045; G02B 5/005; G02B 5/20; G02B 27/0025; G02B 27/646; H04N 5/2254; H04N 5/2257; H04N 5/2258; H04N 5/23296

USPC 359/659, 714, 753, 763

See application file for complete search history.

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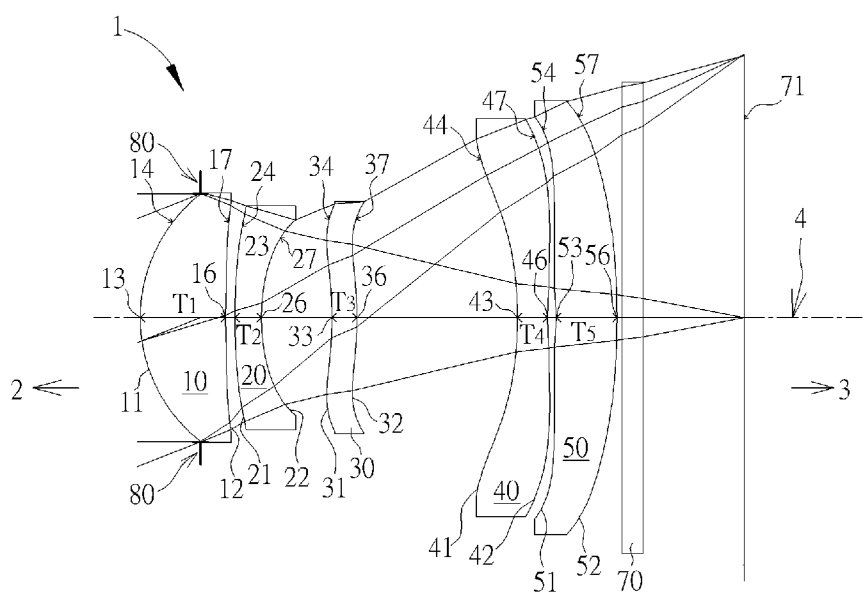
Primary Examiner — Mustak Choudhury
(74) *Attorney, Agent, or Firm* — Winston Hsu

(57) **ABSTRACT**

An optical lens assembly includes a first lens of a concave image surface near its periphery, a second lens of a plastic material, a third lens of a concave object surface near the optical-axis and a concave image surface near its periphery, a fourth lens of a concave object surface near the optical-axis, a fifth lens of a concave object surface near its periphery and a convex image surface near the optical-axis.

18 Claims, 30 Drawing Sheets



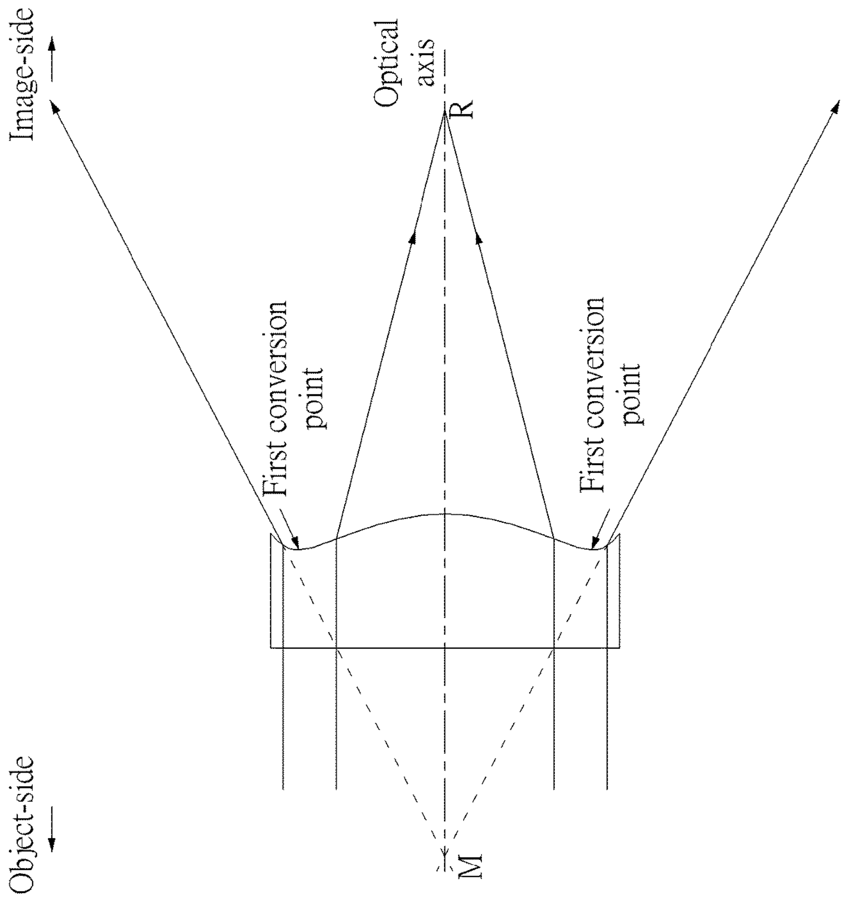


Image-side
Optical axis
R
First conversion point
First conversion point
Object-side
M

FIG. 2

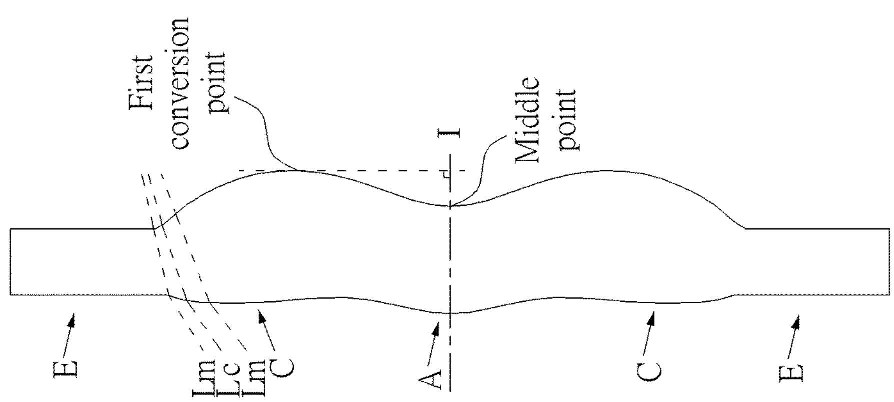

First conversion point
I
Middle point
E
Lm
Lc
Lm
C
A
C
E

FIG. 1

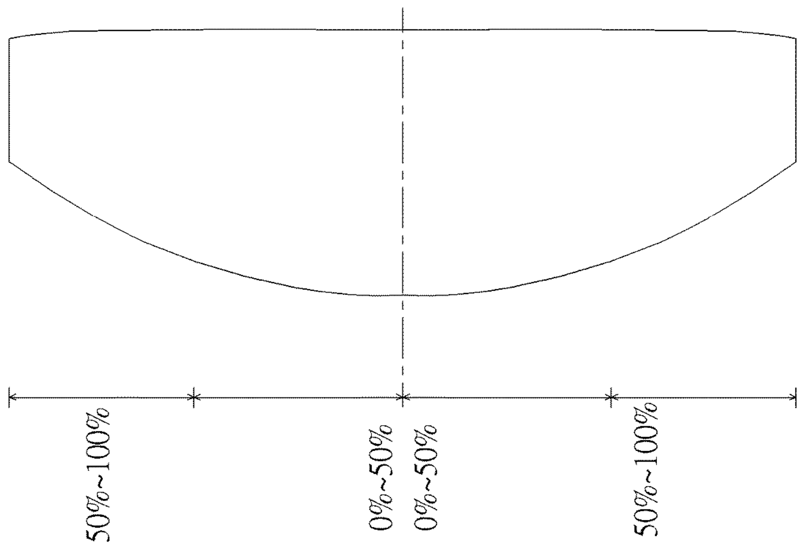


FIG. 5

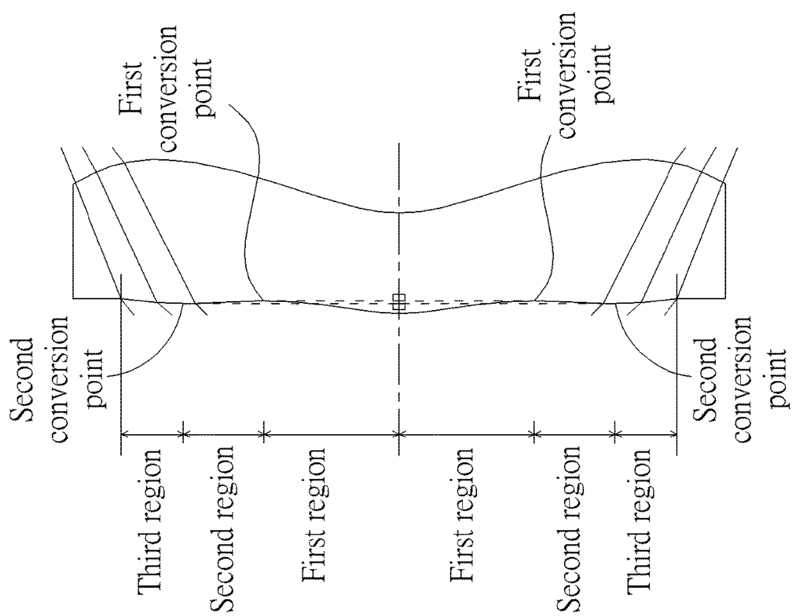


FIG. 4

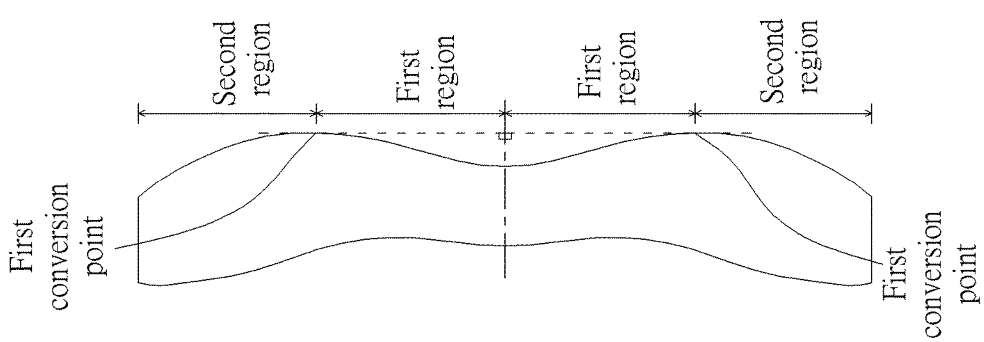


FIG. 3

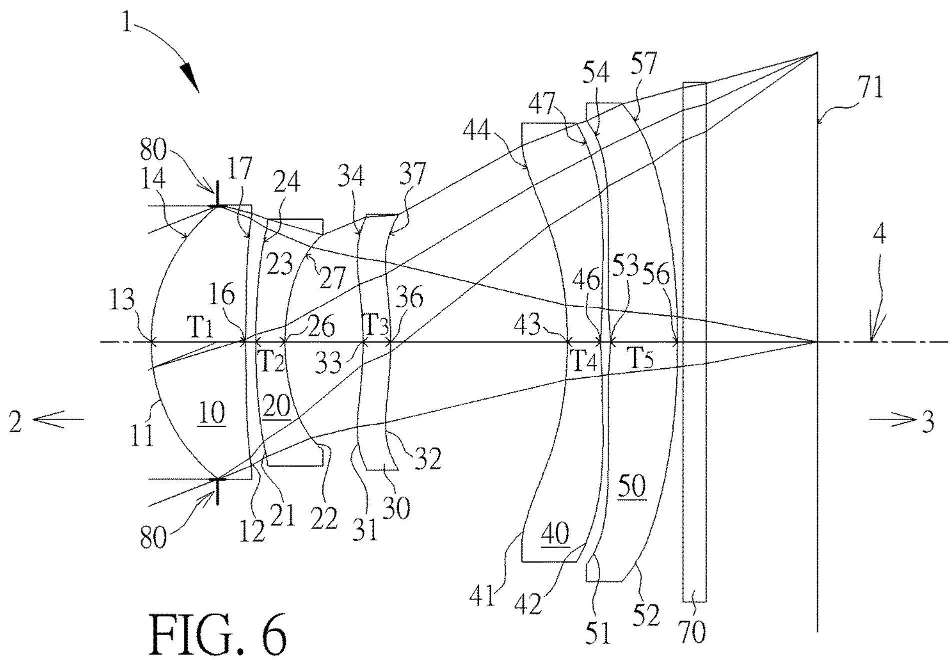


FIG. 6

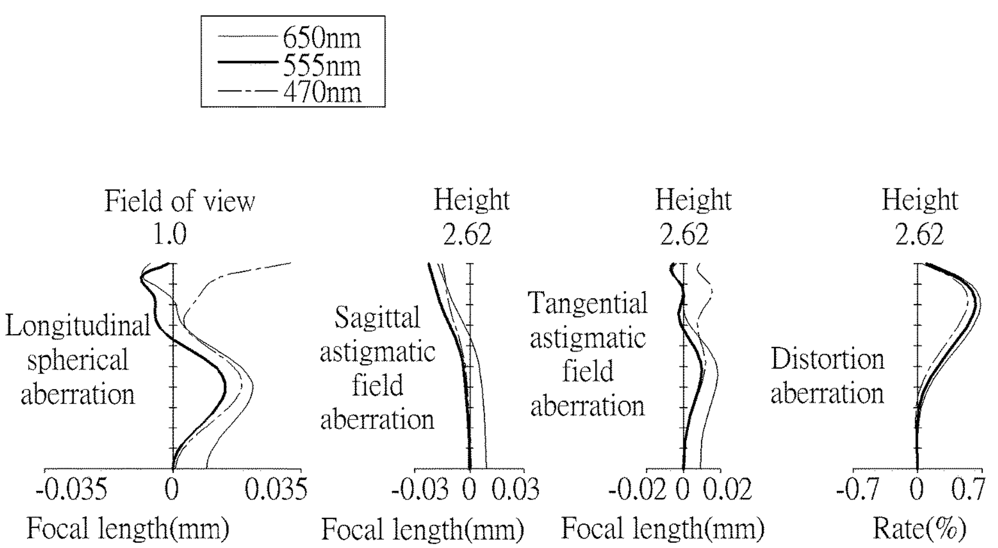


FIG. 7A FIG. 7B FIG. 7C FIG. 7D

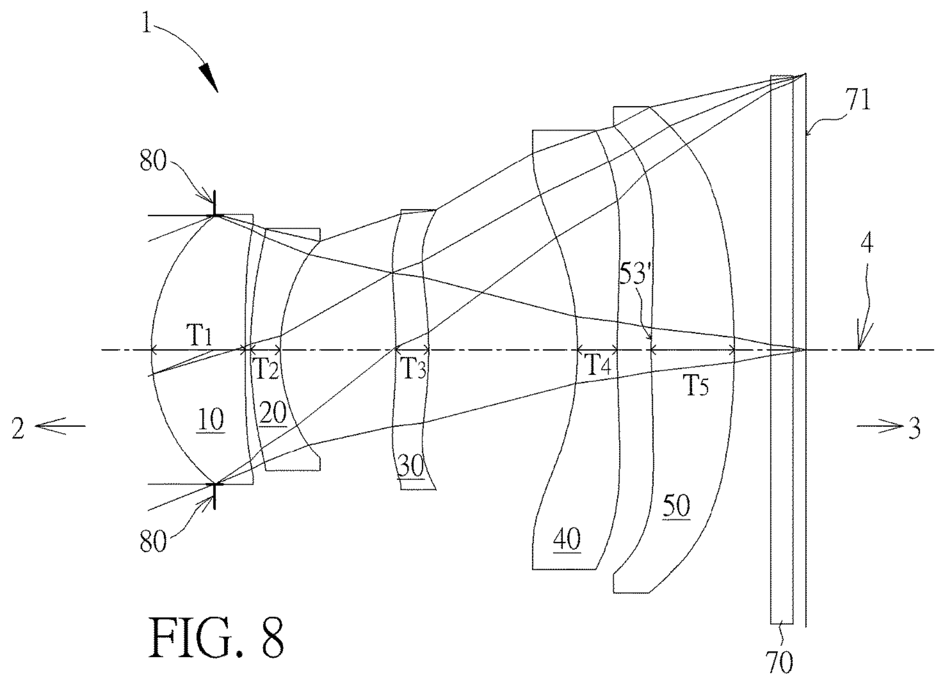


FIG. 8

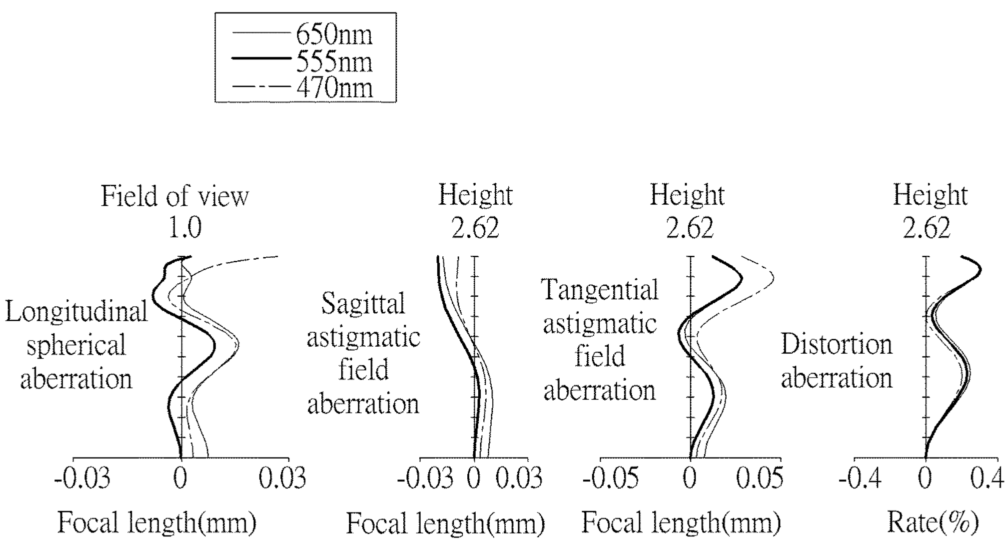


FIG. 9A FIG. 9B FIG. 9C FIG. 9D

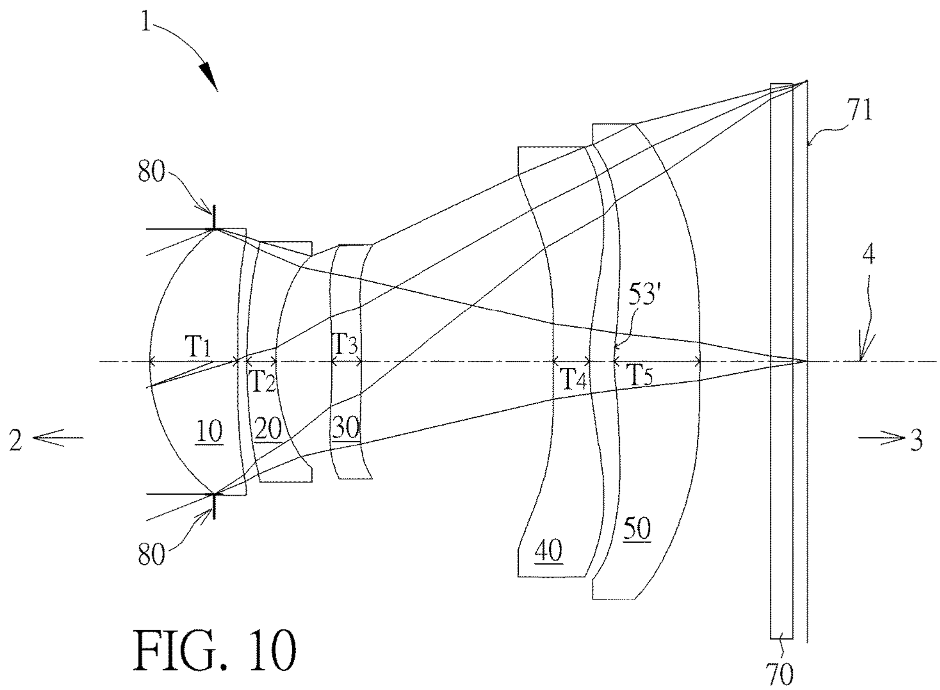


FIG. 10

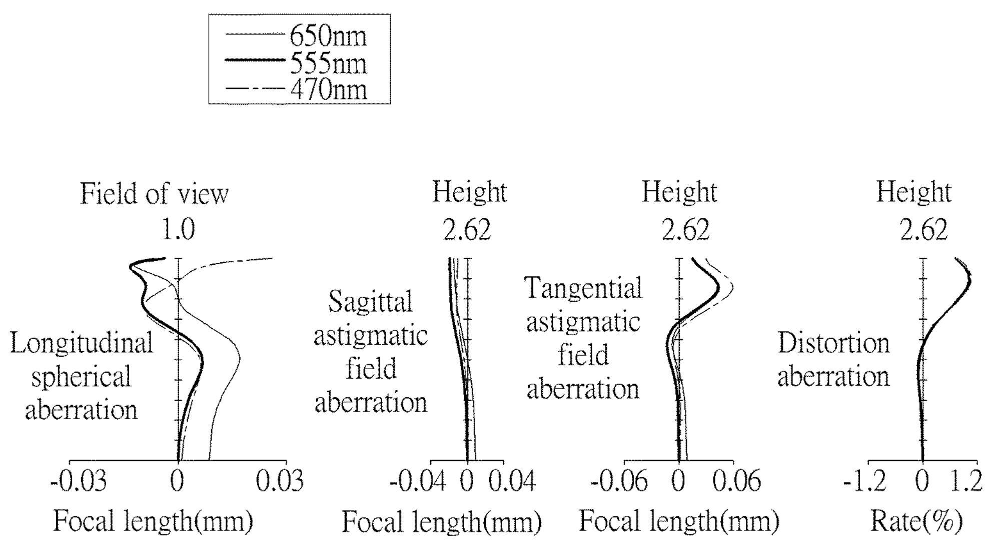


FIG. 11A FIG. 11B FIG. 11C FIG. 11D

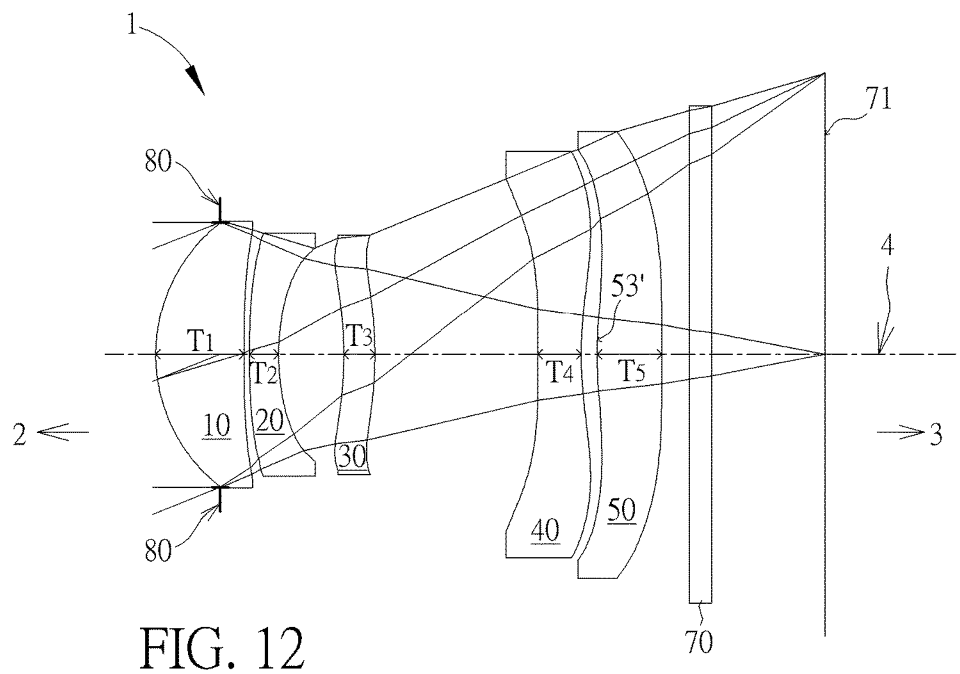


FIG. 12

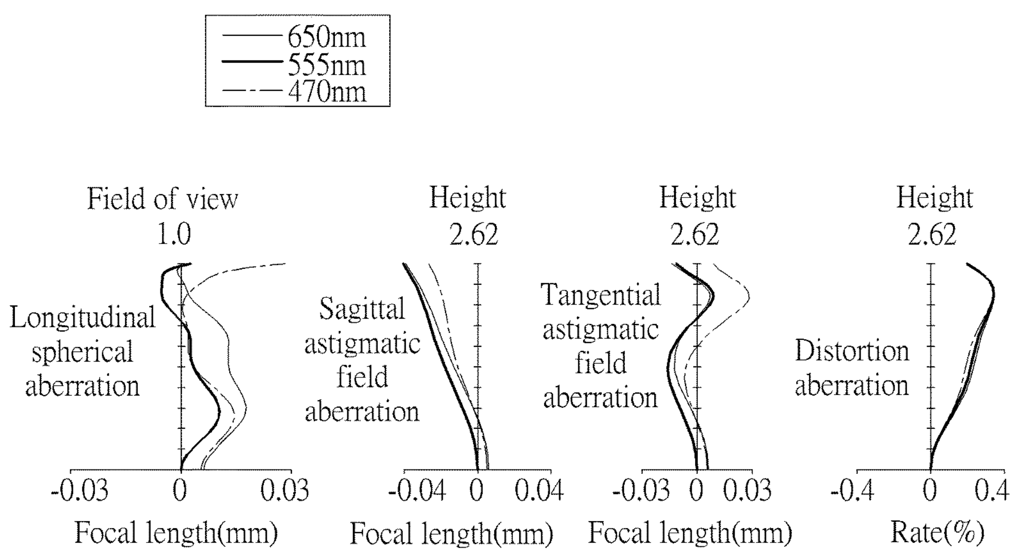


FIG. 13A FIG. 13B FIG. 13C FIG. 13D

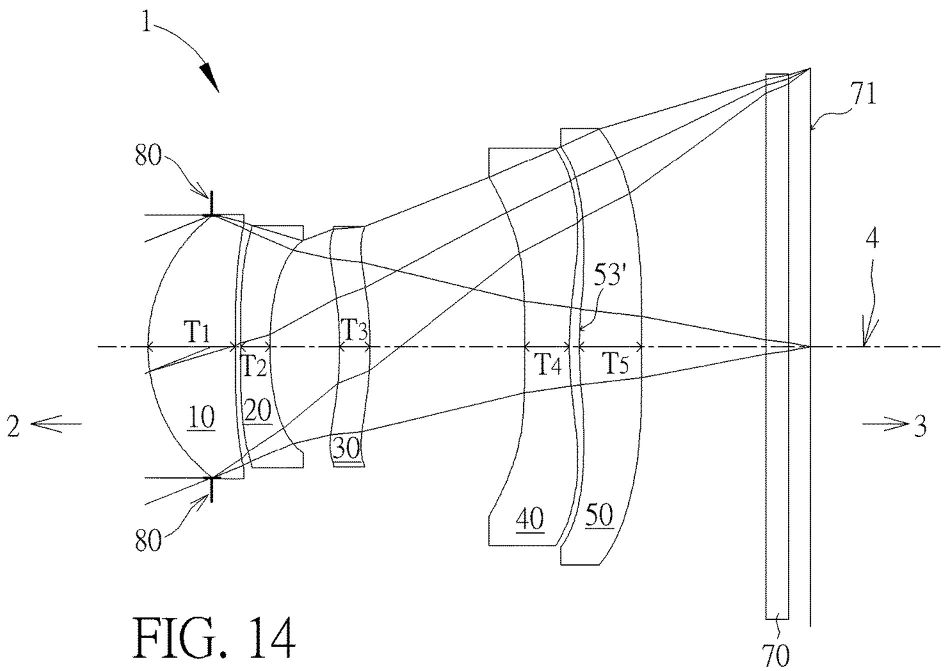


FIG. 14

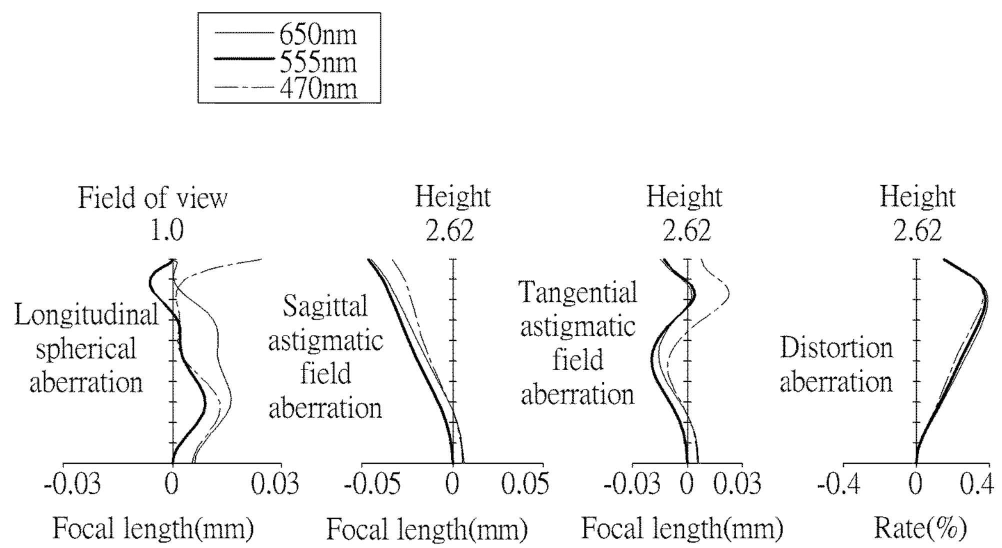


FIG. 15A FIG. 15B FIG. 15C FIG. 15D

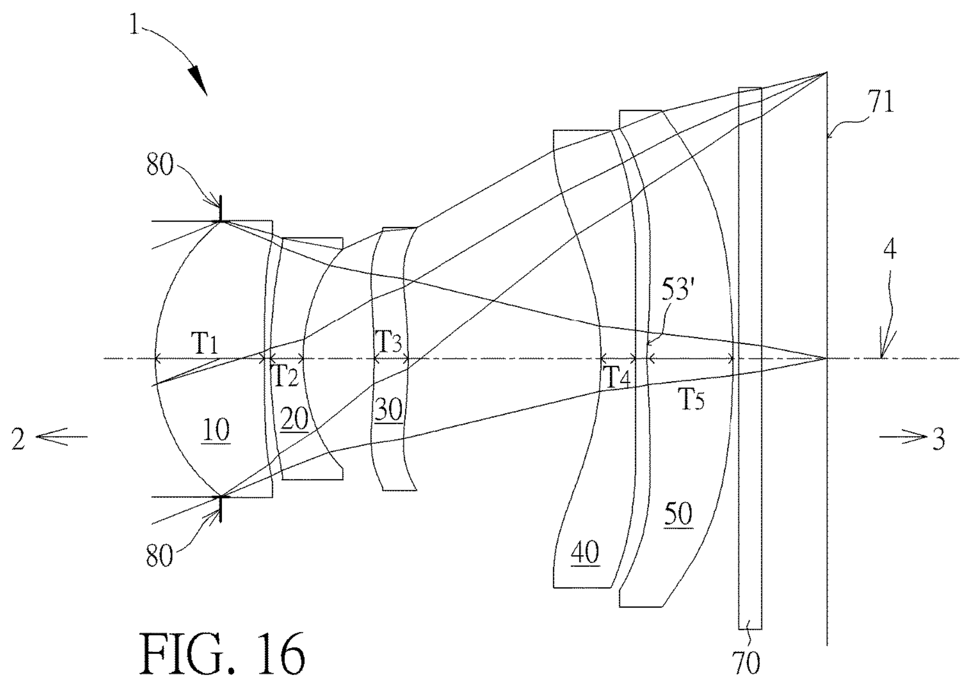


FIG. 16

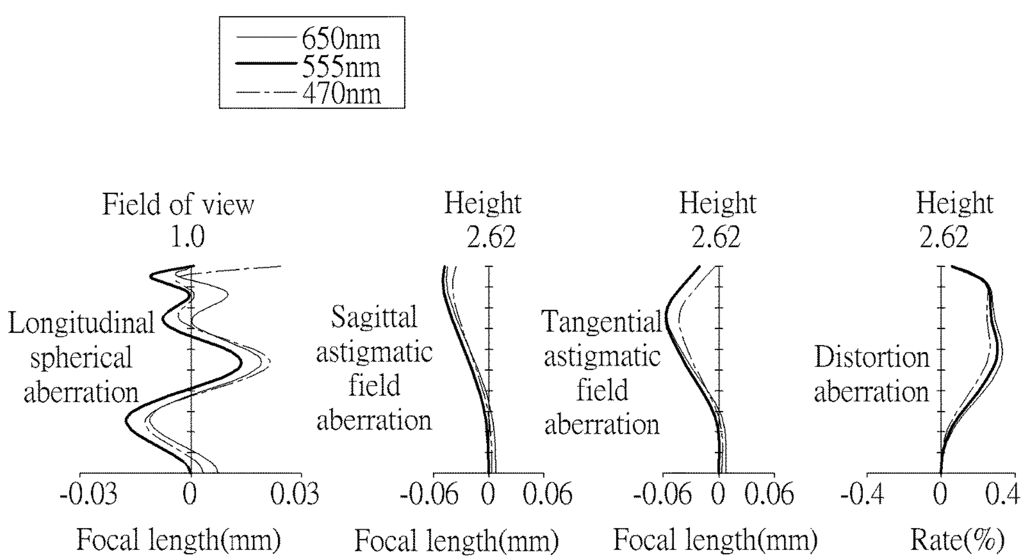


FIG. 17A FIG. 17B FIG. 17C FIG. 17D

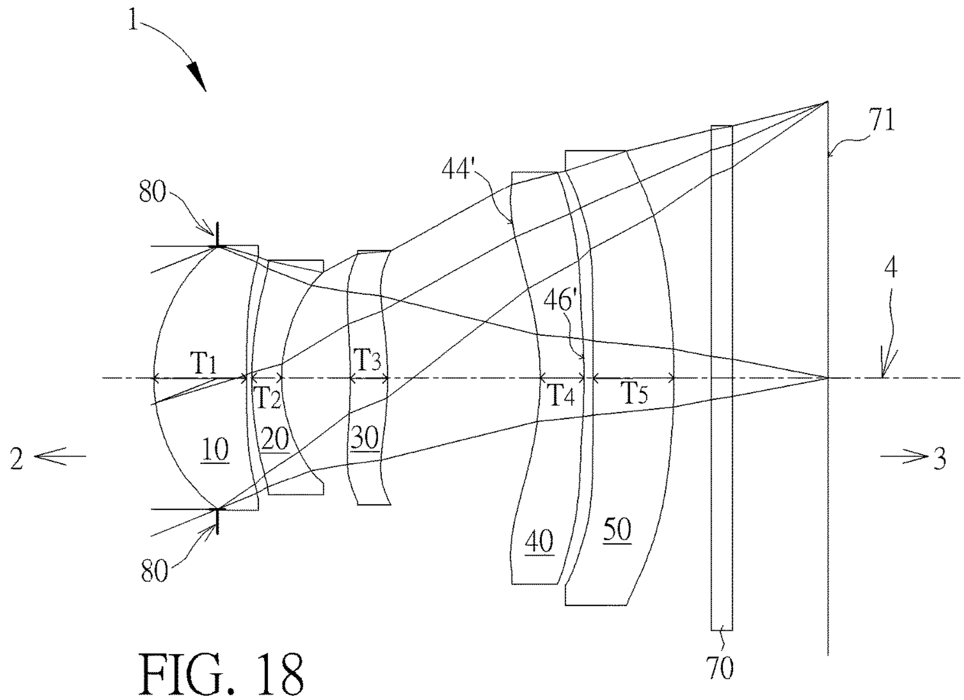


FIG. 18

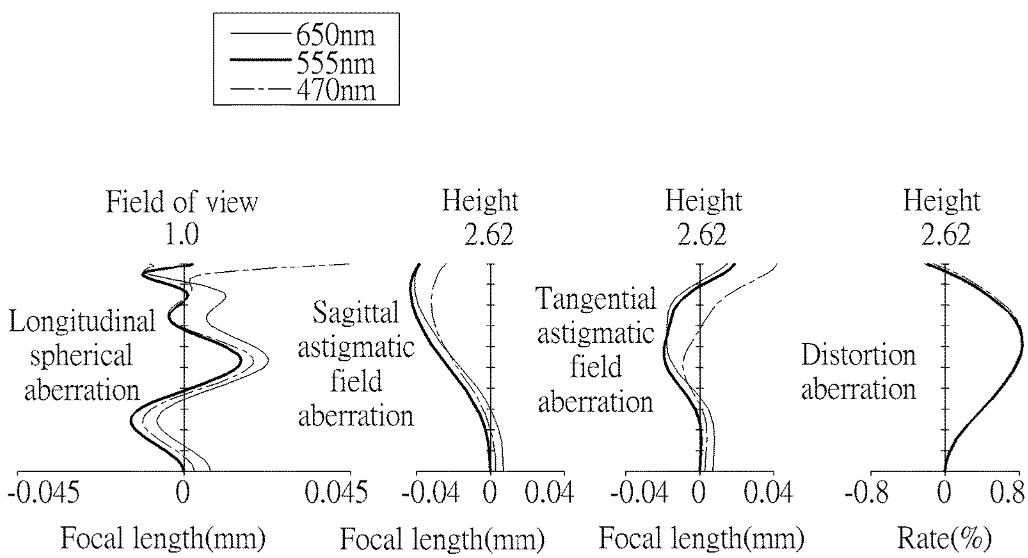


FIG. 19A FIG. 19B FIG. 19C FIG. 19D

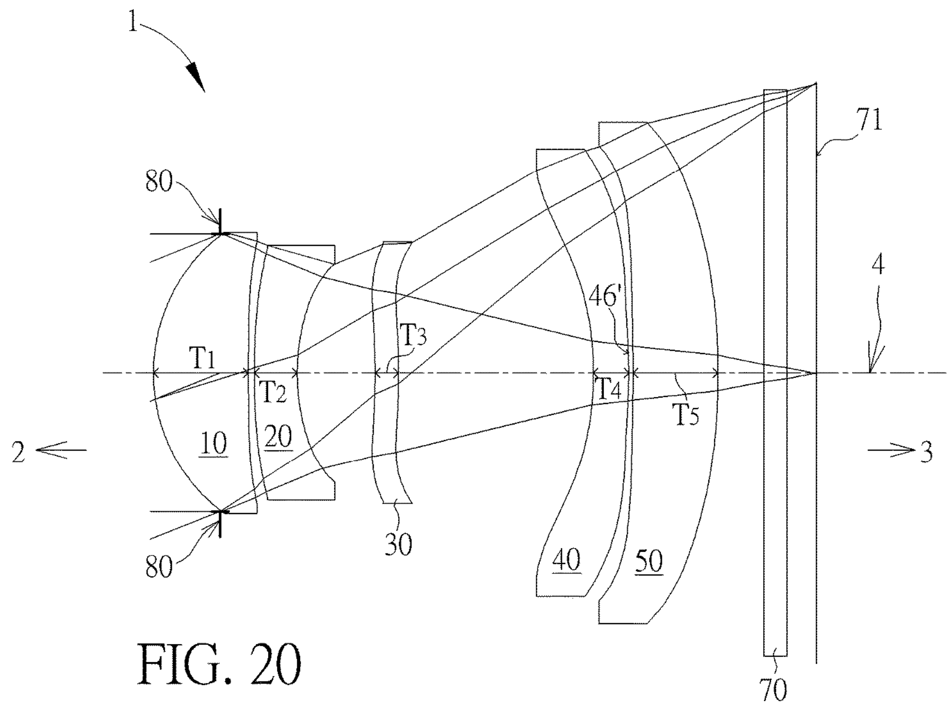


FIG. 20

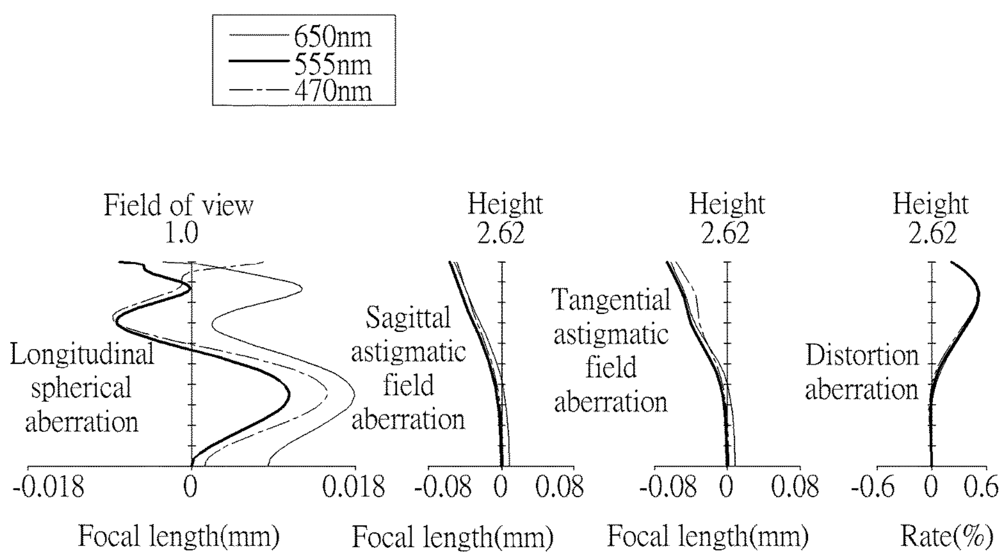


FIG. 21A FIG. 21B FIG. 21C FIG. 21D

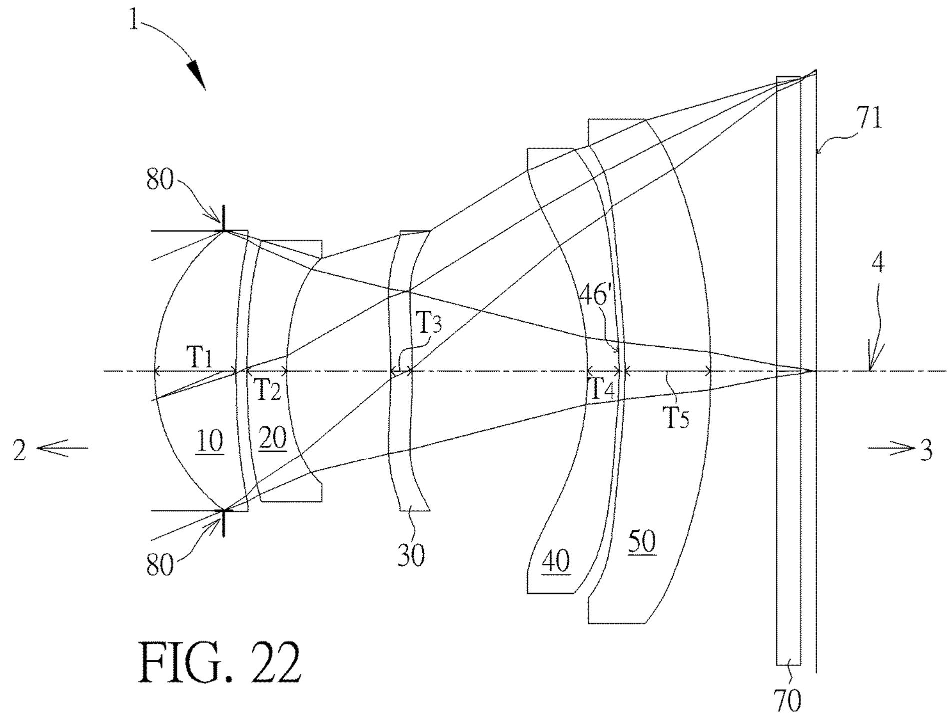


FIG. 22

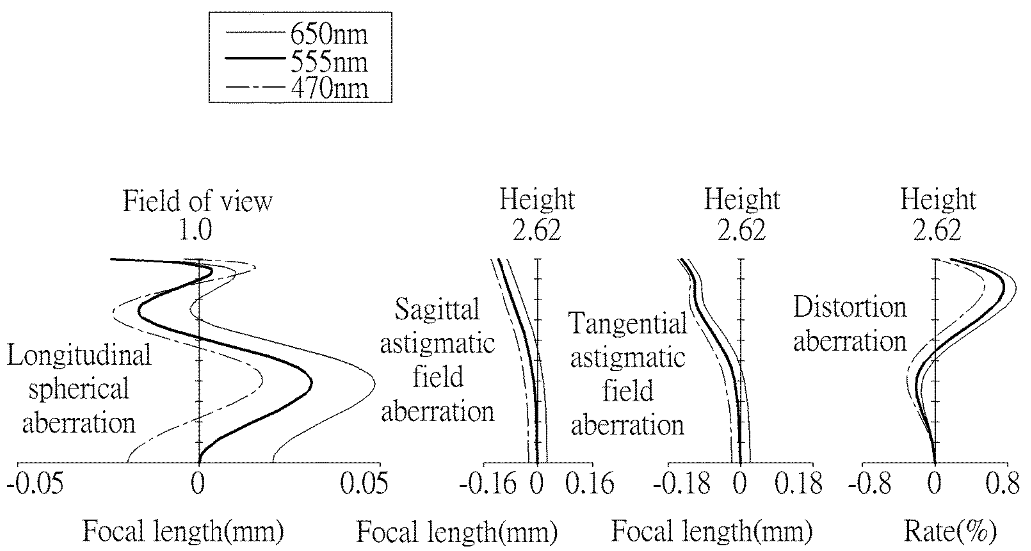


FIG. 23A FIG. 23B FIG. 23C FIG. 23D

First Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.565	0.855	T_1	1.545	55.987	2.975
		34.464	0.088	G_{12}			
21	Second Lens	6.079	0.264	T_2	1.642	22.409	-4.568
22		1.955	0.704	G_{23}			
31	Third Lens	-3.412	0.249	T_3	1.545	55.987	122.164
32		-3.330	1.598	G_{34}			
41	Fourth Lens	-4.283	0.310	T_4	1.545	55.987	-6.178
42		16.327	0.064	G_{45}			
51	Fifth Lens	-61.049	0.619	T_5	1.642	22.409	15.559
52		-8.680	0.050	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	1.007				
71	Image Plane	INFINITY					

FIG. 24

No.	11	12	21	22	31
K	0	0	0	0	0
A2	0	0	0	0	0
A4	-5.1019E-03	-1.1795E-02	-6.1024E-02	-4.1177E-02	4.7114E-02
A6	1.3383E-02	1.0197E-01	2.0203E-01	2.4491E-01	9.3125E-02
A8	-1.4112E-02	-1.4856E-01	-2.7096E-01	-3.4162E-01	1.9493E-02
A10	7.4197E-03	1.2406E-01	2.3818E-01	3.4020E-01	-1.3612E-02
A12	-1.7438E-03	-6.0881E-02	-1.4721E-01	3.1908E-02	-5.9601E-02
A14	8.8342E-04	1.5056E-02	5.5452E-02	-3.1563E-01	5.3499E-02
A16	-3.4323E-04	-1.4388E-03	-9.7610E-03	1.8789E-01	-1.3722E-02
A18	0	0	0	0	0
No.	32	41	42	51	52
K	0	0	0	0	0
A2	0	0	0	0	0
A4	7.7280E-02	-4.3907E-02	-1.6848E-02	1.1605E-02	-1.9702E-02
A6	5.6722E-02	9.9879E-03	-6.2526E-03	-9.0627E-03	5.9705E-03
A8	7.2382E-02	3.3722E-03	2.6595E-03	2.9527E-03	-1.7910E-04
A10	-7.6516E-02	-8.1652E-04	-6.0166E-04	-8.6690E-04	-2.8627E-04
A12	2.3350E-02	1.0548E-05	6.4943E-05	1.2702E-04	3.5737E-05
A14	-6.0913E-03	1.4172E-06	3.4303E-06	-1.2397E-05	-2.9482E-06
A16	1.2750E-03	6.7402E-07	-1.1968E-06	6.6124E-07	3.7681E-07
A18	0	0	0	0	0

FIG. 25

Second Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.673	0.888	T_1	1.545	55.987	3.183
		36.100	0.050	G_{12}			
21	Second Lens	3.742	0.281	T_2	1.642	22.409	-4.631
22		1.615	1.090	G_{23}			
31	Third Lens	-6.554	0.319	T_3	1.545	55.987	14.935
32		-3.697	1.405	G_{34}			
41	Fourth Lens	-3.012	0.378	T_4	1.545	55.987	-4.432
42		12.878	0.331	G_{45}			
51	Fifth Lens	280.676	0.779	T_5	1.642	22.409	10.514
52		-6.967	0.344	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	0.124				
71	Image Plane	INFINITY					

FIG. 26

No.	11	12	21	22	31
K	0	0	0	0	0
A2	0	0	0	0	0
A4	-2.9728E-03	-7.5137E-03	-8.8179E-02	-9.4169E-02	2.1942E-02
A6	1.0298E-02	1.0360E-01	1.8964E-01	2.3403E-01	9.5783E-03
A8	-1.0145E-02	-1.4686E-01	-2.5715E-01	-3.6826E-01	4.8299E-02
A10	7.3044E-03	1.2403E-01	2.4529E-01	3.1543E-01	1.0914E-02
A12	-2.5671E-03	-5.9701E-02	-1.5201E-01	7.5829E-02	-6.4111E-02
A14	6.4345E-04	1.5481E-02	5.1647E-02	-2.9699E-01	3.9393E-02
A16	4.6243E-05	-2.2918E-03	-8.5437E-03	1.3677E-01	-7.9105E-03
A18	0	0	0	0	0
No.	32	41	42	51	52
K	0	0	0	0	0
A2	0	0	0	0	0
A4	4.9053E-02	-1.6436E-02	-1.1008E-02	1.8093E-02	-1.5828E-04
A6	-1.1259E-02	8.2621E-03	-8.6526E-03	-1.4300E-02	-4.0198E-03
A8	9.6745E-02	2.7260E-03	3.1902E-03	3.0994E-03	4.0303E-04
A10	-6.5742E-02	-8.1717E-04	-5.7962E-04	-8.6169E-04	-1.4973E-04
A12	2.2473E-02	3.6789E-05	4.6302E-05	1.4995E-04	3.9210E-05
A14	-7.2925E-03	5.5623E-06	6.6719E-07	-8.7526E-06	-4.5251E-06
A16	1.3121E-03	-3.5047E-07	-2.4364E-07	-1.8402E-07	2.5518E-07
A18	0	0	0	0	0

FIG. 27

Third Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.595	0.819	T_1	1.545	55.987	3.069
		26.778	0.085	G_{12}			
21	Second Lens	5.154	0.269	T_2	1.642	22.409	-4.725
22		1.880	0.521	G_{23}			
31	Third Lens	-7.751	0.278	T_3	1.545	55.987	96.259
32		-6.841	1.788	G_{34}			
41	Fourth Lens	-7299610372	0.335	T_4	1.545	55.987	-4.661
42		2.546	0.250	G_{45}			
51	Fifth Lens	6.916	0.778	T_5	1.642	22.409	9.023
52		-35.907	0.659	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	0.135				
71	Image Plane	INFINITY					

FIG. 28

No.	11	12	21	22	31
K	0	0	0	0	0
A2	0	0	0	0	0
A4	-2.9126E-03	1.0469E-02	-6.6095E-02	-8.5247E-02	2.2015E-02
A6	1.2958E-02	9.5031E-02	1.9428E-01	2.2208E-01	6.1588E-02
A8	-1.0129E-02	-1.5335E-01	-2.7663E-01	-2.7231E-01	3.1033E-02
A10	7.5097E-03	1.2388E-01	2.5252E-01	2.4496E-01	3.8443E-03
A12	-3.4437E-03	-5.7336E-02	-1.5358E-01	5.5130E-02	-5.9126E-02
A14	1.0276E-03	1.6050E-02	6.1075E-02	-2.2157E-01	5.0767E-02
A16	1.2615E-05	-2.6926E-03	-1.3108E-02	1.1704E-01	-1.5969E-02
A18	0	0	0	0	0
No.	32	41	42	51	52
K	0	0	0	0	0
A2	0	0	0	0	0
A4	5.6736E-02	-7.7219E-02	-9.7834E-02	-4.3990E-02	-4.8606E-02
A6	6.7208E-02	9.0702E-03	1.2341E-02	2.6770E-03	6.8278E-03
A8	1.4143E-02	3.4574E-03	4.9479E-04	2.2571E-03	8.8503E-04
A10	-3.2630E-02	-6.5411E-04	-7.1589E-04	-8.4491E-04	-3.3252E-04
A12	4.8411E-02	1.9072E-05	9.2916E-05	1.1165E-04	2.3997E-05
A14	-4.0484E-02	-6.2819E-06	5.5260E-06	-1.0605E-05	-3.8554E-06
A16	9.8413E-03	1.3637E-06	-1.6170E-06	6.7515E-07	5.4683E-07
A18	0	0	0	0	0

FIG. 29

Fourth Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.583	0.820	T_1	1.545	55.987	3.058
		24.734	0.050	G_{12}			
21	Second Lens	9.025	0.274	T_2	1.642	22.409	-4.855
22		2.303	0.604	G_{23}			
31	Third Lens	-3.708	0.290	T_3	1.545	55.987	92.787
32		-3.550	1.522	G_{34}			
41	Fourth Lens	-600.000	0.402	T_4	1.545	55.987	-6.309
42		3.467	0.165	G_{45}			
51	Fifth Lens	9.393	0.585	T_5	1.642	22.409	14.293
52		-600.000	0.255	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	1.057				
71	Image Plane	INFINITY					

FIG. 30

No.	11	12	21	22	31
K	0	0	0	0	0
A2	0	0	0	0	0
A4	8.2938E-04	3.8080E-02	2.6771E-02	2.8009E-02	-1.6209E-02
A6	2.0254E-03	3.6047E-02	9.0436E-02	5.2690E-02	6.1311E-02
A8	1.8575E-04	-1.1231E-01	-2.4471E-01	-1.0382E-02	5.5546E-03
A10	2.2069E-03	1.0365E-01	2.9565E-01	-1.7300E-02	-2.4116E-02
A12	-2.8709E-03	-3.8026E-02	-1.8554E-01	6.9285E-02	9.1931E-02
A14	1.1152E-03	5.6876E-03	6.7652E-02	2.8317E-02	-6.7782E-02
A16	8.2689E-05	-1.1842E-03	-1.4129E-02	-3.2533E-02	1.2155E-02
A18	0	0	0	0	0
No.	32	41	42	51	52
K	0	0	0	0	0
A2	0	0	0	0	0
A4	2.6823E-03	-7.9187E-02	-6.6637E-02	-1.6919E-02	-2.8926E-02
A6	7.1981E-02	1.9492E-02	2.0278E-03	-1.4116E-02	-6.5593E-04
A8	-2.5009E-02	-6.5026E-03	1.1256E-03	5.5040E-03	1.8278E-03
A10	8.8710E-04	2.8990E-03	-4.2163E-04	-7.4947E-04	-3.5900E-04
A12	5.5046E-02	-2.1614E-04	3.4082E-04	9.3477E-05	6.8194E-06
A14	-4.2501E-02	-1.6250E-04	-1.0604E-04	-3.6373E-05	-1.0377E-07
A16	7.1735E-03	2.8709E-05	9.3430E-06	3.9501E-06	3.3328E-07
A18	0	0	0	0	0

FIG. 31

Fifth Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.577	0.818	T_1	1.545	55.987	3.041
		25.443	0.051	G_{12}			
21	Second Lens	65.489	0.276	T_2	1.642	22.409	-5.077
22		3.124	0.653	G_{23}			
31	Third Lens	-3.554	0.286	T_3	1.545	55.987	202.855
32		-3.541	1.457	G_{34}			
41	Fourth Lens	-600.000	0.420	T_4	1.545	55.987	-6.356
42		3.493	0.116	G_{45}			
51	Fifth Lens	10.580	0.561	T_5	1.642	22.409	16.067
52		-600.000	1.175	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	0.206				
71	Image Plane	INFINITY					

FIG. 32

No.	11	12	21	22	31
K	0	0	0	0	0
A2	0	0	0	0	0
A4	1.6556E-04	3.8455E-02	7.1756E-02	8.2021E-02	-8.9856E-03
A6	1.9073E-03	4.7092E-02	7.0617E-02	3.5696E-02	3.2610E-02
A8	9.3008E-04	-1.2824E-01	-2.4957E-01	-5.4173E-02	6.4468E-02
A10	2.4426E-04	1.0647E-01	3.1309E-01	9.2926E-02	-9.9396E-02
A12	-1.0852E-03	-2.9817E-02	-2.0397E-01	-3.7957E-02	1.3777E-01
A14	4.4956E-04	-1.0527E-04	7.8032E-02	5.0837E-02	-8.1907E-02
A16	1.1854E-04	-1.0948E-04	-1.6189E-02	-2.0652E-02	1.4823E-02
A18	0	0	0	0	0
No.	32	41	42	51	52
K	0	0	0	0	0
A2	0	0	0	0	0
A4	-2.5204E-04	-8.9511E-02	-7.2596E-02	-2.4787E-02	-3.6743E-02
A6	5.5460E-02	1.8821E-02	3.9838E-03	-6.0269E-03	4.8303E-03
A8	4.7546E-03	-7.4828E-03	2.7582E-04	3.3924E-03	1.4781E-03
A10	-3.1145E-02	4.1321E-03	-3.2831E-04	-6.8160E-04	-7.3669E-04
A12	6.7153E-02	-2.5785E-04	4.7846E-04	1.3805E-04	7.0425E-05
A14	-3.9030E-02	-3.3044E-04	-1.6839E-04	-5.6614E-05	1.2845E-06
A16	5.4146E-03	6.1636E-05	1.6764E-05	7.4317E-06	-1.5748E-07
A18	0	0	0	0	0

FIG. 33

Sixth Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.650	0.999	T_1	1.545	55.987	3.126
		38.743	0.054	G_{12}			
21	Second Lens	4.093	0.299	T_2	1.642	22.409	-4.231
22		1.594	0.647	G_{23}			
31	Third Lens	-6.554	0.312	T_3	1.545	55.987	20.999
32		-4.241	1.768	G_{34}			
41	Fourth Lens	-3.012	0.314	T_4	1.545	55.987	-5.243
42		60.423	0.128	G_{45}			
51	Fifth Lens	913.527	0.770	T_5	1.642	22.409	10.685
52		-6.967	0.051	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	0.599				
71	Image Plane	INFINITY					

FIG. 34

No.	11	12	21	22	31
K	0	0	0	0	0
A2	0	0	0	0	0
A4	1.6215E-03	-4.0121E-03	-1.1742E-01	-1.3955E-01	3.0933E-02
A6	-1.6791E-03	8.9307E-02	1.8297E-01	2.9202E-01	-4.7143E-02
A8	1.1322E-02	-1.2823E-01	-1.7457E-01	-4.6166E-01	2.4082E-01
A10	-1.2371E-02	1.4610E-01	1.9729E-01	5.9391E-01	-1.5003E-01
A12	4.9537E-03	-8.1866E-02	-1.5889E-01	-1.5844E-01	-2.8195E-02
A14	7.9684E-04	1.5283E-02	5.5188E-02	-3.2283E-01	5.2883E-02
A16	-4.8606E-04	-1.4152E-03	-9.3368E-03	2.0064E-01	-1.3987E-02
A18	0	0	0	0	0
No.	32	41	42	51	52
K	0	0	0	0	0
A2	0	0	0	0	0
A4	5.6353E-02	-2.3530E-02	3.7827E-03	2.3683E-02	-9.3093E-03
A6	-1.5985E-02	2.5314E-02	-1.5706E-02	-2.0409E-02	5.7318E-03
A8	1.3263E-01	-7.4546E-03	5.1905E-03	2.9014E-03	-4.4132E-03
A10	-7.3999E-02	1.5753E-03	-7.5055E-04	5.7421E-05	1.0227E-03
A12	1.1235E-02	-1.6557E-04	3.2226E-05	1.1828E-05	-7.0569E-05
A14	-5.9048E-03	5.1004E-07	4.6718E-06	-1.0612E-05	-3.1651E-06
A16	2.3119E-03	8.0040E-07	-6.3784E-07	6.2308E-07	4.2383E-07
A18	0	0	0	0	0

FIG. 35

Seventh Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.637	0.874	T_1	1.545	55.987	3.305
		14.208	0.050	G_{12}			
21	Second Lens	2.937	0.283	T_2	1.642	22.409	-4.401
22		1.391	0.648	G_{23}			
31	Third Lens	-6.554	0.352	T_3	1.545	55.987	12.858
32		-3.455	1.447	G_{34}			
41	Fourth Lens	-3.012	0.398	T_4	1.545	55.987	-6.777
42		-16.921	0.104	G_{45}			
51	Fifth Lens	-38.583	0.761	T_5	1.642	22.409	13.012
52		-6.967	0.350	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	0.902				
71	Image Plane	INFINITY					

FIG. 36

No.	11	12	21	22	31
K	0	0	0	0	0
A2	0	0	0	0	0
A4	4.4677E-03	2.6722E-02	-9.0381E-02	-1.3593E-01	2.2687E-02
A6	-2.5946E-03	3.0985E-02	9.6463E-02	1.8489E-01	-2.1183E-02
A8	1.1742E-02	-4.6040E-02	-4.6910E-02	-2.4487E-01	1.8453E-01
A10	-1.1083E-02	7.9666E-02	8.2371E-02	3.2849E-01	-1.0869E-01
A12	4.7242E-03	-6.1769E-02	-1.1942E-01	-3.9779E-02	-3.6905E-02
A14	7.9684E-04	1.5283E-02	5.5188E-02	-3.2283E-01	5.2883E-02
A16	-4.8606E-04	-1.4152E-03	-9.3368E-03	2.0064E-01	-1.3987E-02
A18	0	0	0	0	0
No.	32	41	42	51	52
K	0	0	0	0	0
A2	0	0	0	0	0
A4	4.2594E-02	8.7528E-03	2.1845E-02	2.3250E-02	5.8189E-03
A6	2.0471E-02	1.3540E-02	-2.4920E-02	-2.4570E-02	-3.7239E-03
A8	6.3255E-02	-4.2574E-03	7.0674E-03	3.6258E-03	-1.0829E-03
A10	-2.0699E-02	1.0772E-03	-7.0484E-04	4.6631E-04	5.1975E-04
A12	-1.6098E-03	-1.3377E-04	-3.2080E-06	-7.4313E-05	-4.2535E-05
A14	-5.9048E-03	5.1004E-07	4.6718E-06	-1.0612E-05	-3.1651E-06
A16	2.3119E-03	8.0040E-07	-6.3784E-07	6.2308E-07	4.2383E-07
A18	0	0	0	0	0

FIG. 37

Eighth Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.598	0.855	T_1	1.545	55.987	3.048
		32.022	0.053	G_{12}			
21	Second Lens	6.157	0.387	T_2	1.642	22.409	-4.520
22		1.934	0.700	G_{23}			
31	Third Lens	-6.554	0.213	T_3	1.545	55.987	60.689
32		-5.535	1.760	G_{34}			
41	Fourth Lens	-3.012	0.298	T_4	1.545	55.987	-5.956
42		-42.003	0.057	G_{45}			
51	Fifth Lens	-26.222	0.766	T_5	1.642	22.409	14.432
52		-6.967	0.417	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	0.265				
71	Image Plane	INFINITY					

FIG. 38

No.	11	12	21	22	31
K	0	0	0	0	0
A2	0	0	0	0	0
A4	-2.5633E-03	-9.4485E-03	-6.1823E-02	-5.1164E-02	1.7209E-02
A6	8.6618E-03	1.1274E-01	1.9808E-01	2.2513E-01	7.3104E-02
A8	-1.0030E-02	-1.5156E-01	-2.6945E-01	-3.4409E-01	2.0513E-02
A10	7.9467E-03	1.2226E-01	2.5007E-01	3.5287E-01	-5.0509E-03
A12	-3.5806E-03	-5.6714E-02	-1.5612E-01	4.2204E-02	-4.5562E-02
A14	1.4938E-03	1.3455E-02	5.9215E-02	-3.3179E-01	3.7826E-02
A16	-2.6258E-04	-1.8540E-03	-1.1601E-02	1.8940E-01	-1.0261E-02
A18	0	0	0	0	0
No.	32	41	42	51	52
K	0	0	0	0	0
A2	0	0	0	0	0
A4	5.0938E-02	-3.0988E-02	-1.0210E-02	6.8030E-03	-2.2199E-02
A6	5.0181E-02	9.9441E-03	-7.9318E-03	-7.2452E-03	7.7117E-03
A8	9.2786E-02	2.4385E-03	3.0152E-03	2.5422E-03	-8.0926E-04
A10	-1.4892E-01	-8.4126E-04	-7.0113E-04	-8.7070E-04	-1.6059E-04
A12	1.2782E-01	2.1278E-04	6.4388E-05	1.4867E-04	2.9703E-05
A14	-6.6821E-02	-5.3322E-05	1.0135E-05	-1.4952E-05	-2.2789E-06
A16	1.3536E-02	4.9853E-06	-1.9516E-06	7.5850E-07	1.7364E-07
A18	0	0	0	0	0

FIG. 39

Ninth Example							
No.		Curvature Radius	Ape. Stop Distance Lens Thickness Air Gap		Refractive Index	Abbe No.	Focal Length
	Object	INFINITY	INFINITY				
		INFINITY	0.628				
80	Ape. Stop	INFINITY	-0.602				
11	First Lens	1.550	0.709	T_1	1.545	55.987	3.373
		8.167	0.095	G_{12}			
21	Second Lens	6.545	0.347	T_2	1.642	22.409	-6.549
22		2.519	0.905	G_{23}			
31	Third Lens	-6.554	0.190	T_3	1.545	55.987	44.548
32		-5.216	1.531	G_{34}			
41	Fourth Lens	-3.012	0.262	T_4	1.545	55.987	-9.518
42		-7.381	0.063	G_{45}			
51	Fifth Lens	-4.916	0.747	T_5	1.642	22.409	-30.095
52		-6.967	0.580	G_{56}			
70	IR Filter	INFINITY	0.210		1.517	64.167	
		INFINITY	0.138				
71	Image Plane	INFINITY					

FIG. 40

No.	11	12	21	22	31
K	0	0	0	0	0
A2	0	0	0	0	0
A4	-4.5151E-04	-1.8051E-02	-5.6707E-02	-1.4894E-02	4.3068E-02
A6	1.3780E-02	1.0184E-01	2.0331E-01	2.2812E-01	8.7489E-02
A8	-1.4797E-02	-1.4852E-01	-2.7172E-01	-3.2873E-01	9.9532E-03
A10	7.8946E-03	1.2350E-01	2.3936E-01	3.4315E-01	-1.4311E-02
A12	-1.4711E-03	-6.1034E-02	-1.4646E-01	1.5966E-02	-5.9451E-02
A14	7.9684E-04	1.5283E-02	5.5188E-02	-3.2283E-01	5.2883E-02
A16	-4.8606E-04	-1.4152E-03	-9.3368E-03	2.0064E-01	-1.3987E-02
A18	0	0	0	0	0
No.	32	41	42	51	52
K	0	0	0	0	0
A2	0	0	0	0	0
A4	7.2256E-02	-4.5220E-02	1.9757E-02	4.3485E-02	-2.6269E-02
A6	6.1419E-02	1.2292E-02	-1.0136E-02	-1.2078E-02	7.7117E-03
A8	7.2421E-02	3.6278E-03	2.0594E-03	2.5175E-03	-1.1364E-04
A10	-8.2181E-02	-8.2264E-04	-6.3602E-04	-8.8131E-04	-2.9041E-04
A12	2.0403E-02	5.0286E-06	6.4814E-05	1.3537E-04	3.3601E-05
A14	-5.9048E-03	5.1004E-07	4.6718E-06	-1.0612E-05	-3.1651E-06
A16	2.3119E-03	8.0040E-07	-6.3784E-07	6.2308E-07	4.2383E-07
A18	0	0	0	0	0

FIG. 41

Example	1	2	3	4	5	6	7	8	9
f	6.582	6.621	6.6273	6.6102	6.6138	6.5553	6.471	6.5141	6.346
FNO	2.661	2.601	2.6743	2.6751	2.6749	2.603	2.605	2.5924	2.5817
HFOV	21.685	21.550	21.4292	21.5812	21.5801	21.773	22.0796	21.8229	22.3973
T_1	0.855	0.888	0.819	0.820	0.818	0.999	0.874	0.855	0.709
G_{12}	0.088	0.050	0.085	0.050	0.051	0.054	0.050	0.053	0.095
T_2	0.264	0.281	0.269	0.274	0.276	0.299	0.283	0.387	0.347
G_{23}	0.704	1.090	0.521	0.604	0.653	0.647	0.648	0.700	0.905
T_3	0.249	0.319	0.278	0.290	0.286	0.312	0.352	0.213	0.190
G_{34}	1.598	1.405	1.788	1.522	1.457	1.768	1.447	1.760	1.531
T_4	0.310	0.378	0.335	0.402	0.420	0.314	0.398	0.298	0.262
G_{45}	0.064	0.331	0.250	0.165	0.116	0.128	0.104	0.057	0.063
T_5	0.619	0.779	0.778	0.585	0.561	0.770	0.761	0.766	0.747
G_{56}	0.050	0.344	0.659	0.255	1.175	0.051	0.350	0.417	0.580
TF	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210	0.210
GFP	1.007	0.124	0.135	1.057	0.206	0.599	0.902	0.265	0.138
ALT	2.297	2.645	2.479	2.370	2.361	2.694	2.669	2.519	2.255
AAG	2.455	2.876	2.645	2.341	2.277	2.596	2.249	2.570	2.595
BFL	1.267	0.677	1.004	1.523	1.591	0.860	1.463	0.892	0.927
TTL	6.019	6.198	6.129	6.234	6.229	6.150	6.381	5.981	5.777
TTL / T_2	22.790	22.022	22.775	22.790	22.608	20.574	22.560	15.453	16.655
ALT/(G_{12}+G_{45})	15.040	6.952	7.390	11.032	14.133	14.834	17.304	22.890	14.249
ALT / T_2	8.697	9.398	9.213	8.666	8.568	9.013	9.437	6.508	6.501
TTL/(G_{12}+G_{23}+G_{45})	7.028	4.214	7.153	7.609	7.594	7.421	7.952	7.381	5.433
ALT / T_4	7.418	6.997	7.403	5.902	5.621	8.585	6.702	8.443	8.599
TTL/(G_{23}+G_{45})	7.837	4.362	7.944	8.102	8.096	7.937	8.479	7.896	5.967
EFL/(G_{12}+G_{23})	8.310	5.806	10.925	10.103	9.395	9.351	9.269	8.649	6.345
TTL/(T_4+T_5)	6.482	5.358	5.505	6.319	6.347	5.673	5.503	5.618	5.727
EFL/(G_{23}+G_{45})	8.570	4.660	8.590	8.590	8.597	8.460	8.599	8.599	6.554
ALT/(T_2+T_3)	4.473	4.408	4.533	4.204	4.205	4.411	4.201	4.201	4.201
(T_1+T_4)/T_2	4.410	4.499	4.288	4.466	4.493	4.393	4.499	2.979	2.801
EFL/(G_{12}+G_{23}+G_{45})	7.686	4.501	7.735	8.068	8.064	7.910	8.064	8.038	5.968
ALT / G_{34}	1.437	1.883	1.386	1.558	1.620	1.524	1.845	1.431	1.472
EFL / T_5	10.636	8.501	8.514	11.299	11.781	8.510	8.501	8.501	8.500
EFL / G_{34}	4.119	4.713	3.706	4.344	4.540	3.708	4.473	3.701	4.144
TTL/(T_1+T_2)	5.379	5.299	5.632	5.701	5.697	4.737	5.515	4.816	5.470
TTL/(G_{12}+G_{34})	3.569	4.261	3.271	3.967	4.131	3.376	4.263	3.299	3.552
EFL/(T_2+T_4)	11.472	10.040	10.973	9.790	9.510	10.698	9.501	9.504	10.419

FIG. 42

OPTICAL LENS SET

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority from Chinese patent application No. 201610755720.8, filed on Aug. 29, 2016, the contents of which are hereby incorporated by reference in their entirety for all purposes.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to an optical imaging lens set. Specifically speaking, the present invention is directed to an optical imaging lens set of five lens elements for use in mobile phones, in cameras, in tablet personal computers, or in personal digital assistants (PDA).

2. Description of the Prior Art

In recent years, the popularity of mobile phones and digital cameras makes the specifications of various portable electronic products improve quickly, and so does the key component—the optical imaging lens set. However, good and necessary optical properties for taking pictures or recording videos are not enough. There is still a need for telescopic function.

With the development of image sensors, the demands for the imaging quality are getting higher and higher. The conventional size of the telescopic optical imaging lens set is longer than 50 mm and Fno number is over 4. They fail to meet the demands for the specification of current portable electronic products. Accordingly, an optical imaging lens set of telescopic function which has improved imaging quality with reduced lens set size is still needed.

SUMMARY OF THE INVENTION

In light of the above, the present invention proposes an optical imaging lens set which has a reduced optical imaging lens system length and keeps sufficient optical performance. The optical imaging lens set of five lens elements of the present invention from an object side toward an image side in order along an optical axis has a first lens element, a second lens element, a third lens element, a fourth lens element and a fifth lens element. Each lens element has an object-side surface facing toward an object side as well as an image-side surface facing toward an image side. The optical imaging lens set exclusively has the first lens element, the second lens element, the third lens element, the fourth lens element and the fifth lens element with refractive power.

The first lens element has an image-side surface with a concave portion in a vicinity of its periphery. The second lens element is of a plastic material. The third lens element has an object-side surface with a concave portion in a vicinity of the optical-axis and an image-side surface with a concave portion in a vicinity of its periphery. The fourth lens element has an object-side surface with a concave portion in a vicinity of the optical-axis. The fifth lens element has an object-side surface with a concave portion in a vicinity of its periphery and an image-side surface with a convex portion in a vicinity of the optical-axis.

In the optical imaging lens set of five lens elements of the present invention, TTL is a distance from the first object-side surface to an image plane and the second lens element has a second lens element thickness T_2 to satisfy $10.50 \leq TTL/T_2 \leq 22.80$.

In the optical imaging lens set of five lens elements of the present invention, ALT is the total thickness of all five lens elements, an air gap G_{12} between the first lens element and the second lens element along the optical axis and an air gap G_{45} between the fourth lens element and the fifth lens element along the optical axis to satisfy $5.50 \leq ALT/(G_{12}+G_{45})$.

The optical imaging lens set of five lens elements of the present invention satisfies $6.50 \leq ALT/T_2$.

In the optical imaging lens set of five lens elements of the present invention, an air gap G_{23} between the second lens element and the third lens element along the optical axis satisfies $4.20 \leq TTL/(G_{12}+G_{23}+G_{45})$.

In the optical imaging lens set of five lens elements of the present invention, the fourth lens element has a fourth lens element thickness T_4 to satisfy $ALT/T_4 \leq 8.60$.

The optical imaging lens set of five lens elements of the present invention satisfies $4.20 \leq TTL/(G_{23}+G_{45}) \leq 8.50$.

In the optical imaging lens set of five lens elements of the present invention, EFL is the effective focal length of the optical imaging lens set to satisfy $EFL/(G_{12}+G_{23}) \leq 12.70$.

In the optical imaging lens set of five lens elements of the present invention, the fifth lens element has a fifth lens element thickness T_5 to satisfy $TTL/(T_4+T_5) \leq 6.50$.

The optical imaging lens set of five lens elements of the present invention satisfies $EFL/(G_{23}+G_{45}) \leq 8.6$.

In the optical imaging lens set of five lens elements of the present invention, the third lens element has a third lens element thickness T_3 to satisfy $4.20 \leq ALT/(T_2+T_3)$.

In the optical imaging lens set of five lens elements of the present invention, the first lens element has a first lens element thickness T_1 to satisfy $2.80 \leq (T_1+T_4)/T_2 \leq 4.50$.

The optical imaging lens set of five lens elements of the present invention satisfies $EFL/(G_{12}+G_{23}+G_{45}) \leq 10.50$.

In the optical imaging lens set of five lens elements of the present invention, an air gap G_{34} between the third lens element and the fourth lens element along the optical axis satisfies $1.3 \leq ALT/G_{34}$.

The optical imaging lens set of five lens elements of the present invention satisfies $8.50 \leq EFL/T_5 \leq 11.80$.

The optical imaging lens set of five lens elements of the present invention satisfies $3.70 \leq EFL/G_{34} \leq 12.50$.

The optical imaging lens set of five lens elements of the present invention satisfies $4.00 \leq TTL/(T_1+T_2)$.

The optical imaging lens set of five lens elements of the present invention satisfies $3.20 \leq TTL/(G_{12}+G_{34})$.

The optical imaging lens set of five lens elements of the present invention satisfies $9.50 \leq EFL/(T_2+T_4)$.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1-5** illustrates the methods for determining the surface shapes and for determining one region is a region in a vicinity of the optical axis or the region in a vicinity of its circular periphery of one lens element.

FIG. **6** illustrates a first example of the optical imaging lens set of the present invention.

FIG. **7A** illustrates the longitudinal spherical aberration on the image plane of the first example.

FIG. **7B** illustrates the astigmatic aberration on the sagittal direction of the first example.

FIG. **7**C illustrates the astigmatic aberration on the tangential direction of the first example.

FIG. **7**D illustrates the distortion aberration of the first example.

FIG. **8** illustrates a second example of the optical imaging lens set of five lens elements of the present invention.

FIG. **9**A illustrates the longitudinal spherical aberration on the image plane of the second example.

FIG. **9**B illustrates the astigmatic aberration on the sagittal direction of the second example.

FIG. **9**C illustrates the astigmatic aberration on the tangential direction of the second example.

FIG. **9**D illustrates the distortion aberration of the second example.

FIG. **10** illustrates a third example of the optical imaging lens set of five lens elements of the present invention.

FIG. **11**A illustrates the longitudinal spherical aberration on the image plane of the third example.

FIG. **11**B illustrates the astigmatic aberration on the sagittal direction of the third example.

FIG. **11**C illustrates the astigmatic aberration on the tangential direction of the third example.

FIG. **11**D illustrates the distortion aberration of the third example.

FIG. **12** illustrates a fourth example of the optical imaging lens set of five lens elements of the present invention.

FIG. **13**A illustrates the longitudinal spherical aberration on the image plane of the fourth example.

FIG. **13**B illustrates the astigmatic aberration on the sagittal direction of the fourth example.

FIG. **13**C illustrates the astigmatic aberration on the tangential direction of the fourth example.

FIG. **13**D illustrates the distortion aberration of the fourth example.

FIG. **14** illustrates a fifth example of the optical imaging lens set of five lens elements of the present invention.

FIG. **15**A illustrates the longitudinal spherical aberration on the image plane of the fifth example.

FIG. **15**B illustrates the astigmatic aberration on the sagittal direction of the fifth example.

FIG. **15**C illustrates the astigmatic aberration on the tangential direction of the fifth example.

FIG. **15**D illustrates the distortion aberration of the fifth example.

FIG. **16** illustrates a sixth example of the optical imaging lens set of five lens elements of the present invention.

FIG. **17**A illustrates the longitudinal spherical aberration on the image plane of the sixth example.

FIG. **17**B illustrates the astigmatic aberration on the sagittal direction of the sixth example.

FIG. **17**C illustrates the astigmatic aberration on the tangential direction of the sixth example.

FIG. **17**D illustrates the distortion aberration of the sixth example.

FIG. **18** illustrates a seventh example of the optical imaging lens set of five lens elements of the present invention.

FIG. **19**A illustrates the longitudinal spherical aberration on the image plane of the seventh example.

FIG. **19**B illustrates the astigmatic aberration on the sagittal direction of the seventh example.

FIG. **19**C illustrates the astigmatic aberration on the tangential direction of the seventh example.

FIG. **19**D illustrates the distortion aberration of the seventh example.

FIG. **20** illustrates an eighth example of the optical imaging lens set of five lens elements of the present invention.

FIG. **21**A illustrates the longitudinal spherical aberration on the image plane of the eighth example.

FIG. **21**B illustrates the astigmatic aberration on the sagittal direction of the eighth example.

FIG. **21**C illustrates the astigmatic aberration on the tangential direction of the eighth example.

FIG. **21**D illustrates the distortion aberration of the eighth example.

FIG. **22** illustrates a ninth example of the optical imaging lens set of five lens elements of the present invention.

FIG. **23**A illustrates the longitudinal spherical aberration on the image plane of the ninth example.

FIG. **23**B illustrates the astigmatic aberration on the sagittal direction of the ninth example.

FIG. **23**C illustrates the astigmatic aberration on the tangential direction of the ninth example.

FIG. **23**D illustrates the distortion aberration of the ninth example.

FIG. **24** shows the optical data of the first example of the optical imaging lens set.

FIG. **25** shows the aspheric surface data of the first example.

FIG. **26** shows the optical data of the second example of the optical imaging lens set.

FIG. **27** shows the aspheric surface data of the second example.

FIG. **28** shows the optical data of the third example of the optical imaging lens set.

FIG. **29** shows the aspheric surface data of the third example.

FIG. **30** shows the optical data of the fourth example of the optical imaging lens set.

FIG. **31** shows the aspheric surface data of the fourth example.

FIG. **32** shows the optical data of the fifth example of the optical imaging lens set.

FIG. **33** shows the aspheric surface data of the fifth example.

FIG. **34** shows the optical data of the sixth example of the optical imaging lens set.

FIG. **35** shows the aspheric surface data of the sixth example.

FIG. **36** shows the optical data of the seventh example of the optical imaging lens set.

FIG. **37** shows the aspheric surface data of the seventh example.

FIG. **38** shows the optical data of the eighth example of the optical imaging lens set.

FIG. **39** shows the aspheric surface data of the eighth example.

FIG. **40** shows the optical data of the ninth example of the optical imaging lens set.

FIG. **41** shows the aspheric surface data of the ninth example.

FIG. **42** shows some important ratios in the examples.

DETAILED DESCRIPTION

Before the detailed description of the present invention, the first thing to be noticed is that in the present invention, similar (not necessarily identical) elements are labeled as the same numeral references. In the entire present specification, “a certain lens element has negative/positive refractive power” refers to the part in a vicinity of the optical axis of

the lens element has negative/positive refractive power calculated by Gaussian optical theory. An object-side/image-side surface refers to the region which allows imaging light passing through, in the drawing, imaging light includes Lc (chief ray) and Lm (marginal ray). As shown in FIG. **1**, the optical axis is "I" and the lens element is symmetrical with respect to the optical axis I. The region A that near the optical axis and for light to pass through is the region in a vicinity of the optical axis, and the region C that the marginal ray passing through is the region in a vicinity of a certain lens element's circular periphery. In addition, the lens element may include an extension part E for the lens element to be installed in an optical imaging lens set (that is the region outside the region C perpendicular to the optical axis). Ideally speaking, no light would pass through the extension part, and the actual structure and shape of the extension part is not limited to this and may have other variations. For the reason of simplicity, the extension part is not illustrated in the following examples. More, precisely, the method for determining the surface shapes or the region in a vicinity of the optical axis, the region in a vicinity of its circular periphery and other regions is described in the following paragraphs:

1. FIG. **1** is a radial cross-sectional view of a lens element. Before determining boundaries of those aforesaid portions, two referential points should be defined first, middle point and conversion point. The middle point of a surface of a lens element is a point of intersection of that surface and the optical axis. The conversion point is a point on a surface of a lens element, where the tangent line of that point is perpendicular to the optical axis. Additionally, if multiple conversion points appear on one single surface, then these conversion points are sequentially named along the radial direction of the surface with numbers starting from the first conversion point. For instance, the first conversion point (closest one to the optical axis), the second conversion point, and the N^{th} conversion point (farthest one to the optical axis within the scope of the clear aperture of the surface). The portion of a surface of the lens element between the middle point and the first conversion point is defined as the portion in a vicinity of the optical axis. The portion located radially outside of the N^{th} conversion point (but still within the scope of the clear aperture) is defined as the portion in a vicinity of a periphery of the lens element. In some embodiments, there are other portions existing between the portion in a vicinity of the optical axis and the portion in a vicinity of a periphery of the lens element; the numbers of portions depend on the numbers of the conversion point(s). In addition, the radius of the clear aperture (or a so-called effective radius) of a surface is defined as the radial distance from the optical axis I to a point of intersection of the marginal ray Lm and the surface of the lens element.
2. Referring to FIG. **2**, determining the shape of a portion is convex or concave depends on whether a collimated ray passing through that portion converges or diverges. That is, while applying a collimated ray to a portion to be determined in terms of shape, the collimated ray passing through that portion will be bended and the ray itself or its extension line will eventually meet the optical axis. The shape of that portion can be determined by whether the ray or its extension line meets (intersects) the optical axis (focal point) at the object-side or image-side. For instance, if the ray itself intersects the optical axis at the image side of the lens element after passing through a portion, i.e. the focal point of this ray is at the image side (see point R in FIG. **2**), the portion will be determined as having a convex shape. On the contrary, if the ray diverges after passing through a portion, the extension line of the ray intersects the optical axis at the object side of the lens element, i.e. the focal point of the ray is at the object side (see point M in FIG. **2**), that portion will be determined as having a concave shape. Therefore, referring to FIG. **2**, the portion between the middle point and the first conversion point has a convex shape, the portion located radially outside of the first conversion point has a concave shape, and the first conversion point is the point where the portion having a convex shape changes to the portion having a concave shape, namely the border of two adjacent portions. Alternatively, there is another common way for a person with ordinary skill in the art to tell whether a portion in a vicinity of the optical axis has a convex or concave shape by referring to the sign of an "R" value, which is the (paraxial) radius of curvature of a lens surface. The R value is commonly used in conventional optical design software such as Zemax and CodeV. The R value usually appears in the lens data sheet in the software. For an object-side surface, positive R means that the object-side surface is convex, and negative R means that the object-side surface is concave. Conversely, for an image-side surface, positive R means that the image-side surface is concave, and negative R means that the image-side surface is convex. The result found by using this method should be consistent as by using the other way mentioned above, which determines surface shapes by referring to whether the focal point of a collimated ray is at the object side or the image side.
3. For none conversion point cases, the portion in a vicinity of the optical axis is defined as the portion between 0~50% of the effective radius (radius of the clear aperture) of the surface, whereas the portion in a vicinity of a periphery of the lens element is defined as the portion between 50~100% of effective radius (radius of the clear aperture) of the surface.

Referring to the first example depicted in FIG. **3**, only one conversion point, namely a first conversion point, appears within the clear aperture of the image-side surface of the lens element. Portion I is a portion in a vicinity of the optical axis, and portion II is a portion in a vicinity of a periphery of the lens element. The portion in a vicinity of the optical axis is determined as having a concave surface due to the R value at the image-side surface of the lens element is positive. The shape of the portion in a vicinity of a periphery of the lens element is different from that of the radially inner adjacent portion, i.e. the shape of the portion in a vicinity of a periphery of the lens element is different from the shape of the portion in a vicinity of the optical axis; the portion in a vicinity of a periphery of the lens element has a convex shape.

Referring to the second example depicted in FIG. **4**, a first conversion point and a second conversion point exist on the object-side surface (within the clear aperture) of a lens element. In which portion I is the portion in a vicinity of the optical axis, and portion III is the portion in a vicinity of a periphery of the lens element. The portion in a vicinity of the optical axis has a convex shape because the R value at the object-side surface of the lens element is positive. The portion in a vicinity of a periphery of the lens element (portion III) has a convex shape. What is more, there is another portion having a concave shape existing between the first and second conversion point (portion II).

Referring to a third example depicted in FIG. **5**, no conversion point exists on the object-side surface of the lens

element. In this case, the portion between 0~50% of the effective radius (radius of the clear aperture) is determined as the portion in a vicinity of the optical axis, and the portion between 50~100% of the effective radius is determined as the portion in a vicinity of a periphery of the lens element. The portion in a vicinity of the optical axis of the object-side surface of the lens element is determined as having a convex shape due to its positive R value, and the portion in a vicinity of a periphery of the lens element is determined as having a convex shape as well.

As shown in FIG. **6**, the optical imaging lens set **1** of five lens elements of the present invention, sequentially located from an object side **2** (where an object is located) to an image side **3** along an optical axis **4**, has an aperture stop (ape. stop) **80**, a first lens element **10**, a second lens element **20**, a third lens element **30**, a fourth lens element **40**, a fifth lens element **50**, a filter **70** and an image plane **71**. Generally speaking, the first lens element **10**, the second lens element **20**, the third lens element **30**, the fourth lens element **40** and the fifth lens element **50** may be made of a transparent plastic material but the present invention is not limited to this, and each lens element has an appropriate refractive power. There are exclusively five lens elements, which means the first lens element **10**, the second lens element **20**, the third lens element **30**, the fourth lens element **40** and the fifth lens element **50** with refractive power in the optical imaging lens set **1** of the present invention. The optical axis **4** is the optical axis of the entire optical imaging lens set **1**, and the optical axis of each of the lens elements coincides with the optical axis of the optical imaging lens set **1**.

Furthermore, the optical imaging lens set **1** includes an aperture stop (ape. stop) **80** disposed in an appropriate position. In FIG. **6**, the aperture stop **80** is disposed between the object side **2** and the first lens element **10**. When light emitted or reflected by an object (not shown) which is located at the object side **2** enters the optical imaging lens set **1** of the present invention, it forms a clear and sharp image on the image plane **71** at the image side **3** after passing through the aperture stop **80**, the first lens element **10**, the second lens element **20**, the third lens element **30**, the fourth lens element **40**, the fifth lens element **50** and the filter **70**. In one embodiments of the present invention, the optional filter **70** may be a filter of various suitable functions. For example, the filter **70** may be an infrared cut filter (IR cut filter), placed between the image-side surface **52** of the fifth lens element **50** and the image plane **71**.

Each lens element in the optical imaging lens set **1** of the present invention has an object-side surface facing toward the object side **2** as well as an image-side surface facing toward the image side **3**. For example, the first lens element **10** has a first object-side surface **11** and a first image-side surface **12**; the second lens element **20** has a second object-side surface **21** and a second image-side surface **22**; the third lens element **30** has a third object-side surface **31** and a third image-side surface **32**; the fourth lens element **40** has a fourth object-side surface **41** and a fourth image-side surface **42**; the fifth lens element **50** has a fifth object-side surface **51** and a fifth image-side surface **52**. In addition, each object-side surface and image-side surface in the optical imaging lens set **1** of the present invention has a part (or portion) in a vicinity of its circular periphery (circular periphery part) away from the optical axis **4** as well as a part in a vicinity of the optical axis (optical axis part) close to the optical axis **4**.

Each lens element in the optical imaging lens set **1** of the present invention further has a central thickness T on the optical axis **4**. For example, the first lens element **10** has a first lens element thickness T_1, the second lens element **20** has a second lens element thickness T_2, the third lens element **30** has a third lens element thickness T_3, the fourth lens element **40** has a fourth lens element thickness T_4, the fifth lens element **50** has a fifth lens element thickness T_5. Therefore, the total thickness of all the lens elements in the optical imaging lens set **1** along the optical axis **4** is $ALT=T_1+T_2+T_3+T_4+T_5$.

In addition, between two adjacent lens elements in the optical imaging lens set **1** of the present invention there is an air gap along the optical axis **4**. For example, an air gap G_{12} is disposed between the first lens element **10** and the second lens element **20**, an air gap G_{23} is disposed between the second lens element **20** and the third lens element **30**, an air gap G_{34} is disposed between the third lens element **30** and the fourth lens element **40**, as well as an air gap G_{45} is disposed between the fourth lens element **40** and the fifth lens element **50**. Therefore, the sum of total five air gaps between adjacent lens elements from the first lens element **10** to the fifth lens element **50** along the optical axis **4** is $AAG=G_{12}+G_{23}+G_{34}+G_{45}$.

In addition, the distance between the first object-side surface **11** of the first lens element **10** and the image plane **71**, namely the total length of the optical imaging lens set **1**, along the optical axis **4** is TTL. EFL represents the effective focal length of the optical imaging lens set **1**.

Furthermore, the focal length of the first lens element **10** is f1; the focal length of the second lens element **20** is f2; the focal length of the third lens element **30** is f3; the focal length of the fourth lens element **40** is f4; the focal length of the fifth lens element **50** is f5; the refractive index of the first lens element **10** is n1; the refractive index of the second lens element **20** is n2; the refractive index of the third lens element **30** is n3; the refractive index of the fourth lens element **40** is n4; the refractive index of the fifth lens element **50** is n5; the Abbe number of the first lens element **10** is υ1; the Abbe number of the second lens element **20** is υ2; the Abbe number of the third lens element **30** is υ3; and the Abbe number of the fourth lens element **40** is υ4; the Abbe number of the fifth lens element **50** is υ5.

FIRST EXAMPLE

Please refer to FIG. **6** which illustrates the first example of the optical imaging lens set **1** of the present invention. Please refer to FIG. **7**A for the longitudinal spherical aberration on the image plane **71** of the first example; please refer to FIG. **7**B for the astigmatic field aberration on the sagittal direction; please refer to FIG. **7**C for the astigmatic field aberration on the tangential direction, and please refer to FIG. **7**D for the distortion aberration. The Y axis of the spherical aberration in each example is "field of view" for 1.0. The Y axis of the astigmatic field and the distortion in each example stands for "image height", which is 2.62 mm.

The optical imaging lens set **1** of the first example has five lens elements **10** to **50** with refractive power. The optical imaging lens set **1** also has a filter **70**, an aperture stop **80**, and an image plane **71**. The aperture stop **80** is provided between the object side **2** and the first lens element **10**. The filter **70** may be used for preventing specific wavelength light (such as the infrared light) reaching the image plane to adversely affect the imaging quality.

The first lens element **10** has positive refractive power. The first object-side surface **11** facing toward the object side **2** has a convex part **13** in the vicinity of the optical axis and a convex part **14** in a vicinity of its circular periphery. The first image-side surface **12** facing toward the image side **3**

has a concave part **16** in the vicinity of the optical axis and a concave part **17** in a vicinity of its circular periphery. Besides, both the first object-side surface **11** and the first image-side **12** of the first lens element **10** are aspherical surfaces.

The second lens element **20** is of a plastic material and has negative refractive power. The second object-side surface **21** facing toward the object side **2** has a convex part **23** in the vicinity of the optical axis and a convex part **24** in a vicinity of its circular periphery. The second image-side surface **22** facing toward the image side **3** has a concave part **26** in the vicinity of the optical axis and a concave part **27** in a vicinity of its circular periphery. Both the second object-side surface **21** and the second image-side **22** of the second lens element **20** are aspherical surfaces.

The third lens element **30** has positive refractive power. The third object-side surface **31** facing toward the object side **2** has a concave part **33** in the vicinity of the optical axis and a convex part **34** in a vicinity of its circular periphery. The third image-side surface **32** facing toward the image side **3** has a convex part **36** in the vicinity of the optical axis and a concave part **37** in a vicinity of its circular periphery. Both the third object-side surface **31** and the third image-side **32** of the third lens element **30** are aspherical surfaces.

The fourth lens element **40** has negative refractive power. The fourth object-side surface **41** facing toward the object side **2** has a concave part **43** in the vicinity of the optical axis and a concave part **44** in a vicinity of its circular periphery. The fourth image-side surface **42** facing toward the image side **3** has a concave part **46** in the vicinity of the optical axis and a convex part **47** in a vicinity of its circular periphery. Both the fourth object-side surface **41** and the fourth image-side **42** of the fourth lens element **40** are aspherical surfaces.

The fifth lens element **50** has positive refractive power. The fifth object-side surface **51** facing toward the object side **2** has a concave part **53** in the vicinity of the optical axis and a concave part **54** in a vicinity of its circular periphery. The fifth image-side surface **52** facing toward the image side **3** has a convex part **56** in the vicinity of the optical axis and a convex part **57** in a vicinity of its circular periphery. Both the fifth object-side surface **51** and the fifth image-side **52** of the fifth lens element **50** are aspherical surfaces.

In the first lens element **10**, the second lens element **20**, the third lens element **30**, the fourth lens element **40** and the fifth lens element **50** of the optical imaging lens element **1** of the present invention, there are 10 surfaces, such as the object-side surfaces **11**/**21**/**31**/**41**/**51** and the image-side surfaces **12**/**22**/**32**/**42**/**52**. If a surface is aspherical, these aspheric coefficients are defined according to the following formula:

$$Z(Y) = \frac{Y^2}{R} \Bigg/ \left(1 + \sqrt{1 - (1+K)\frac{Y^2}{R^2}}\right) + \sum_{i=1}^{n} a_i \times Y^i$$

In which:

R represents the curvature radius of the lens element surface;

Z represents the depth of an aspherical surface (the perpendicular distance between the point of the aspherical surface at a distance Y from the optical axis and the tangent plane of the vertex on the optical axis of the aspherical surface);

Y represents a vertical distance from a point on the aspherical surface to the optical axis;

K is a conic constant;

a_i is the aspheric coefficient of the i^{th} order.

The optical data of the first example of the optical imaging lens set **1** are shown in FIG. **24** while the aspheric surface data are shown in FIG. **25**. In the present examples of the optical imaging lens set, the f-number of the entire optical lens element system is Fno, EFL is the effective focal length, HFOV stands for the half field of view which is half of the field of view of the entire optical lens element system, and the unit for the curvature radius, the thickness and the focal length is in millimeters (mm). TTL is 6.0187 mm. Fno is 2.6614. The image height is 2.62 mm. HFOV is 21.6855 degrees.

SECOND EXAMPLE

Please refer to FIG. **8** which illustrates the second example of the optical imaging lens set **1** of the present invention. It is noted that from the second example to the following examples, in order to simplify the figures, only the components different from what the first example has, and the basic lens elements will be labeled in figures. Other components that are the same as what the first example has, such as the object-side surface, the image-side surface, the part in a vicinity of the optical axis and the part in a vicinity of its circular periphery will be omitted in the following examples. Please refer to FIG. **9**A for the longitudinal spherical aberration on the image plane **71** of the second example, please refer to FIG. **9**B for the astigmatic aberration on the sagittal direction, please refer to FIG. **9**C for the astigmatic aberration on the tangential direction, and please refer to FIG. **9**D for the distortion aberration. The components in the second example are similar to those in the first example, but the optical data such as the curvature radius, the refractive power, the lens thickness, the lens focal length, the aspheric surface or the back focal length in this example are different from the optical data in the first example, and in this example, the fifth object-side surface **51** has a convex part **53'** in the vicinity of the optical axis.

The optical data of the second example of the optical imaging lens set are shown in FIG. **26** while the aspheric surface data are shown in FIG. **27**. TTL is 6.1984 mm. Fno is 2.6014. The image height is 2.62 mm. HFOV is 21.5504 degrees. In particular, 1) the HFOV of the second example is smaller than that of the first example of the present invention.

THIRD EXAMPLE

Please refer to FIG. **10** which illustrates the third example of the optical imaging lens set **1** of the present invention. Please refer to FIG. **11**A for the longitudinal spherical aberration on the image plane **71** of the third example; please refer to FIG. **11**B for the astigmatic aberration on the sagittal direction; please refer to FIG. **11**C for the astigmatic aberration on the tangential direction, and please refer to FIG. **11**D for the distortion aberration. The components in the third example are similar to those in the first example, but the optical data such as the curvature radius, the refractive power, the lens thickness, the lens focal length, the aspheric surface or the back focal length in this example are different from the optical data in the first example, and in this example, the fifth object-side surface **51** has a convex part **53'** in the vicinity of the optical axis.

The optical data of the third example of the optical imaging lens set are shown in FIG. **28** while the aspheric surface data are shown in FIG. **29**. TTL is 6.1287 mm. Fno is 2.6744. The image height is 2.62 mm. HFOV is 21.4292

degrees. In particular, 1) the HFOV of the third example is smaller than that of the first example of the present invention.

FOURTH EXAMPLE

Please refer to FIG. **12** which illustrates the fourth example of the optical imaging lens set **1** of the present invention. Please refer to FIG. **13**A for the longitudinal spherical aberration on the image plane **71** of the fourth example; please refer to FIG. **13**B for the astigmatic aberration on the sagittal direction; please refer to FIG. **13**C for the astigmatic aberration on the tangential direction, and please refer to FIG. **13**D for the distortion aberration. The components in the fourth example are similar to those in the first example, but the optical data such as the curvature radius, the refractive power, the lens thickness, the lens focal length, the aspheric surface or the back focal length in this example are different from the optical data in the first example, and in this example, the fifth object-side surface **51** has a convex part **53'** in the vicinity of the optical axis.

The optical data of the fourth example of the optical imaging lens set are shown in FIG. **30** while the aspheric surface data are shown in FIG. **31**. TTL is 6.2344 mm. Fno is 2.6751. The image height is 2.62 mm. HFOV is 21.5813 degrees. In particular, 1) the HFOV of the fourth example is smaller than that of the first example of the present invention.

FIFTH EXAMPLE

Please refer to FIG. **14** which illustrates the fifth example of the optical imaging lens set **1** of the present invention. Please refer to FIG. **15**A for the longitudinal spherical aberration on the image plane **71** of the fifth example; please refer to FIG. **15**B for the astigmatic aberration on the sagittal direction; please refer to FIG. **15**C for the astigmatic aberration on the tangential direction, and please refer to FIG. **15**D for the distortion aberration. The components in the fifth example are similar to those in the first example, but the optical data such as the curvature radius, the refractive power, the lens thickness, the lens focal length, the aspheric surface or the back focal length in this example are different from the optical data in the first example, and in this example, the fifth object-side surface **51** has a convex part **53'** in the vicinity of the optical axis.

The optical data of the fifth example of the optical imaging lens set are shown in FIG. **32** while the aspheric surface data are shown in FIG. **33**. TTL is 6.2285 mm. Fno is 2.6750. The image height is 2.62 mm. HFOV is 21.5801 degrees. In particular, 1) the Fno of the fifth example is larger than that of the first example of the present invention, 2) the HFOV of the fifth example is smaller than that of the first example.

SIXTH EXAMPLE

Please refer to FIG. **16** which illustrates the sixth example of the optical imaging lens set **1** of the present invention. Please refer to FIG. **17**A for the longitudinal spherical aberration on the image plane **71** of the sixth example; please refer to FIG. **17**B for the astigmatic aberration on the sagittal direction; please refer to FIG. **17**C for the astigmatic aberration on the tangential direction, and please refer to FIG. **17**D for the distortion aberration. The components in the sixth example are similar to those in the first example, but the optical data such as the curvature radius, the refractive power, the lens thickness, the lens focal length, the aspheric surface or the back focal length in this example are different from the optical data in the first example, and in this example, the fifth object-side surface **51** has a convex part **53'** in the vicinity of the optical axis.

The optical data of the sixth example of the optical imaging lens set are shown in FIG. **34** while the aspheric surface data are shown in FIG. **35**. TTL is 6.1503 mm. Fno is 2.6030. The image height is 2.62 mm. HFOV is 21.7730 degrees. In particular, 1) the aperture stop of the sixth example is larger than that of the first example of the present invention.

SEVENTH EXAMPLE

Please refer to FIG. **18** which illustrates the seventh example of the optical imaging lens set **1** of the present invention. Please refer to FIG. **19**A for the longitudinal spherical aberration on the image plane **71** of the seventh example; please refer to FIG. **19**B for the astigmatic aberration on the sagittal direction; please refer to FIG. **19**C for the astigmatic aberration on the tangential direction, and please refer to FIG. **19**D for the distortion aberration. The components in the seventh example are similar to those in the first example, but the optical data such as the curvature radius, the refractive power, the lens thickness, the lens focal length, the aspheric surface or the back focal length in this example are different from the optical data in the first example, and in this example, the fourth object-side surface **41** has a convex part **44'** in a vicinity of its circular periphery and the fourth image-side surface **42** has a convex part **46'** in the vicinity of the optical axis.

The optical data of the seventh example of the optical imaging lens set are shown in FIG. **36** while the aspheric surface data are shown in FIG. **37**. TTL is 6.3808 mm. Fno is 2.6051. The image height is 2.62 mm. HFOV is 22.0796 degrees. In particular, 1) the aperture stop of the sixth example is larger than that of the first example of the present invention.

EIGHTH EXAMPLE

Please refer to FIG. **20** which illustrates the eighth example of the optical imaging lens set **1** of the present invention. Please refer to FIG. **21**A for the longitudinal spherical aberration on the image plane **71** of the eighth example; please refer to FIG. **21**B for the astigmatic aberration on the sagittal direction; please refer to FIG. **21**C for the astigmatic aberration on the tangential direction, and please refer to FIG. **21**D for the distortion aberration. The components in the eighth example are similar to those in the first example, but the optical data such as the curvature radius, the refractive power, the lens thickness, the lens focal length, the aspheric surface or the back focal length in this example are different from the optical data in the first example, and in this example, the fourth image-side surface **42** has a convex part **46'** in the vicinity of the optical axis.

The optical data of the eighth example of the optical imaging lens set are shown in FIG. **38** while the aspheric surface data are shown in FIG. **39**. TTL is 5.9812 mm. Fno is 2.5925. The image height is 2.62 mm. HFOV is 21.8230 degrees. In particular, 1) the TTL of the eighth example is shorter than that of the first example of the present invention, 2) the aperture stop of the eighth example is larger than that of the first example of the present invention.

NINTH EXAMPLE

Please refer to FIG. **22** which illustrates the ninth example of the optical imaging lens set **1** of the present invention.

Please refer to FIG. **23**A for the longitudinal spherical aberration on the image plane **71** of the ninth example; please refer to FIG. **23**B for the astigmatic aberration on the sagittal direction; please refer to FIG. **23**C for the astigmatic aberration on the tangential direction, and please refer to FIG. **23**D for the distortion aberration. The components in the ninth example are similar to those in the first example, but the optical data such as the curvature radius, the refractive power, the lens thickness, the lens focal length, the aspheric surface or the back focal length in this example are different from the optical data in the first example, and in this example, the fifth lens element **50** has negative refractive power and the fourth image-side surface **42** has a convex part **46'** in the vicinity of the optical axis.

The optical data of the ninth example of the optical imaging lens set are shown in FIG. **40** while the aspheric surface data are shown in FIG. **41**. TTL is 5.7772 mm. Fno is 2.5818. The image height is 2.62 mm. HFOV is 22.3974 degrees. In particular, 1) the TTL of the ninth example is shorter than that of the first example of the present invention, 2) the aperture stop of the ninth example is larger than that of the first example of the present invention.

Some important ratios in each example are shown in FIG. **42**. The distance between the fifth image-side surface **52** of the fifth lens element **50** to the image plane **71** along the optical axis **4** is BFL; the air gap between the fifth lens element **50** and the filter **70** along the optical axis **4** is GSF; the thickness of the filter **70** along the optical axis **4** is TF; the distance between the filter **70** to the image plane **71** along the optical axis **4** is GFP. Therefore, BFL=G**5**F+TF+GFP.

In the light of the above examples, the inventors observe at least the following features:

1. The present invention proposes finely designed vicinity of the optical axis of a lens element or finely designed vicinity of its periphery. The first lens element has an image-side surface with a concave portion in a vicinity of its periphery to recover light of larger angle.
2. The third lens element has an object-side surface with a concave portion in a vicinity of the optical-axis and an image-side surface with a concave portion in a vicinity of its periphery to concentrate light effectively.
3. The fourth lens element has an object-side surface with a concave portion in a vicinity of the optical-axis to synergistically correct the aberration.
4. The fifth lens element has an object-side surface with a concave portion in a vicinity of its periphery and an image-side surface with a convex portion in a vicinity of the optical-axis to synergistically decrease the length of the optical imaging lens set and to ensure good imaging quality.

In addition, the inventors discover that there are some better ratio ranges for different data according to the above various important ratios. Better ratio ranges help the designers to design a better optical performance and practically possible optical imaging lens set. For example:

1. Any one of the following conditions shows a smaller numerator when the denominator is fixed to exhibit the decrease of the total size:

$$TTL/T_2 \leq 22.80;$$

$$ALT/T_4 \leq 8.60;$$

$$TTL/(G_{23}+G_{45}) \leq 8.50;$$

$$EFL/(G_{12}+G_{23}) \leq 12.70;$$

$$TTL/(T_4+T_5) \leq 6.50;$$

$$EFL/(G_{23}+G_4) \leq 8.6;$$

$$(T_1+T_4)/T_2 \leq 4.50;$$

$$EFL/(G_{12}+G_{23}+G_{45}) \leq 10.50;$$

$$EFL/T_5 \leq 11.80;$$

$$EFL/G_{34} \leq 12.50.$$

When the following conditions are further met, better imaging quality is possible:

$$10.50 \leq TTL/T_2 \leq 22.80;$$

$$4.20 \leq TTL/(G_{23}+G_{45}) \leq 8.50;$$

$$2.80 \leq (T_1+T_4)/T_2 \leq 4.50;$$

$$8.50 \leq EFL/T_5 \leq 11.80;$$

$$3.70 \leq EFL/G_{34} \leq 12.50.$$

When one of the following conditions is met, it shows better arrangements to provide better imaging quality when good yield is maintained:

$$5.50 \leq ALT/(G_{12}+G_{45});$$

$$6.50 \leq ALT/T_2;$$

$$4.20 \leq TTL/(G_{12}+G_{23}+G_{45});$$

$$4.20 \leq ALT/(T_2+T_3);$$

$$1.3 \leq ALT/G_{34};$$

$$4.00 \leq TTL/(T_1+T_2);$$

$$3.20 \leq TTL/(G_{12}+G_{34});$$

$$9.50 \leq EFL/(T_2+T_4).$$

When any one of the following conditions is further met, it additionally keeps a suitable size:

$$5.50 \leq ALT/(G_{12}+G_{45}) \leq 22.90;$$

$$6.50 \leq ALT/T_2 \leq 9.50;$$

$$4.20 \leq TTL/(G_{12}+G_{23}+G_{45}) \leq 8.0;$$

$$4.20 \leq ALT/(T_2+T_3) \leq 4.60;$$

$$1.3 \leq ALT/G_{34} \leq 1.90\ ;$$

$$4.00 \leq TTL/(T_1+T_2) \leq 5.80;$$

$$3.20 \leq TTL/(G_{12}+G_{34}) \leq 4.30;$$

$$9.50 \leq EFL/(T_2+T_4) \leq 11.50.$$

When any one of the following conditions is further met, it helps reduce the total length of the optical imaging lens set without overly compromising the telescopic function.

$$TTL/T_2 \leq 22.8;$$

$$ALT/T_4 \leq 8.60;$$

$$TTL/(G_{23}+G_{45}) \leq 8.50;$$

$$TTL/(T_4+T_5) \leq 6.50;$$

$$(T_1+T_4)/T_2 \leq 4.50.$$

It is preferably:

$$10.50 \leq TTL/T_2 \leq 22.8;$$

$$5.60 \leq ALT/T_4 \leq 8.60;$$

$$4.20 \leq TTL/(G_{23}+G_{45}) \leq 8.50;$$

$$5.30 \leq TTL/(T_4+T_5) \leq 6.50;$$

$$2.80 \leq (T_1+T4)/T_2 \leq 4.50;$$

to overly increase the total length of the optical imaging lens set when the telescopic function is overly enhanced.

With respect to:

$$EFL/(G_{12}+G_{23}) \leq 12.70;$$

$$EFL/(G_{23}+G_{45}) \leq 8.60;$$

$$EFL/(G_{12}+G_{23}+G_{45}) \leq 10.50;$$

$$EFL/T_5 \leq 11.80;$$

$$EFL/G_{34} \leq 12.50;$$

by limiting the relationship amongst EFL, the length thickness and the air gaps, it helps enhance the telescopic function without compromising the imaging quality. It is preferably:

$$5.80 \leq EFL/(G_{12}+G_{23}) \leq 12.70;$$

$$4.60 \leq EFL/(G_{23}+G_{45}) \leq 8.60;$$

$$4.50 \leq EFL/(G_{12}+G_{23}+G_{45}) \leq 10.50;$$

$$8.5 \leq EFL/T_5 \leq 11.80;$$

$$3.70 \leq EFL/G_{34} \leq 12.50,$$

in order to keep each thickness of the lens element and each air gap in preferred ranges. A good ratio helps to control the lens thickness or the air gaps to maintain a suitable range and keeps a lens element from being too thick to facilitate the reduction of the overall size or too thin to assemble the optical imaging lens set.

With respect to:

$$5.5 \leq ALT/(G_{12}+G_{45});$$

$$6.5 \leq ALT/T_2;$$

$$4.2 \leq TTL/(G_{12}+G_{23}+G_{45});$$

$$4.2 \leq ALT/(T_2+T_3);$$

$$1.3 \leq ALT/G_{34};$$

$$4.0 \leq TTL/(T_1+T_2);$$

$$3.20 \leq TTL/(G_{12}+G_{34});$$

$$9.50 \leq EFL/(T_2+T_4);$$

it is preferably:

$$5.5 \leq ALT/(G_{12}+G_{45}) \leq 22.90;$$

$$6.5 \leq ALT/T_2 \leq 9.50;$$

$$4.2 \leq TTL/(G_{12}+G_{23}+G_{45}) \leq 8.0;$$

$$4.2 \leq ALT/(T_2+T_3) \leq 4.60;$$

$$1.3 \leq ALT/G_{34} \leq 1.90;$$

$$4.0 \leq TTL/(T_1+T_2) \leq 5.80;$$

$$3.20 \leq TTL/(G_{12}+G_{34}) \leq 4.30;$$

$$9.50 \leq EFL/(T_2+T_4) \leq 11.50$$

in order to keep each thickness of the lens element and each air gap in preferred ranges, good ratio helps to control the lens thickness or the air gaps to maintain a suitable range and keeps a lens element from being too thick to facilitate the reduction of the overall size or too thin to assemble the optical imaging lens set.

The above limitations may be properly combined at the discretion of persons who practice the present invention and they are not limited as shown above. In the light of the unpredictability of the optical imaging lens set, the present invention suggests the above principles to appropriately reduce the length of the lens element set, to have better F number, to have better imaging quality or to have better assembling yield to overcome the shortcomings of prior art.

The above-mentioned one or more conditions may be properly combined in the embodiments. In addition to the above ratios, the curvatures of each lens element or multiple lens elements may be fine-tuned to result in more fine structures to enhance the performance or the resolution. For example, the first object-side surface **11** of the first lens element **10** may additionally have a convex part in the vicinity of the optical axis. The above limitations may be properly combined in the embodiments without causing inconsistency.

In each one of the above examples, the longitudinal spherical aberration, the astigmatic aberration and the distortion aberration meet requirements in use. By observing three representative wavelengths of red, green and blue, it is suggested that all curves of every wavelength are close to one another, which reveals off-axis light of different heights of every wavelength all concentrates on the image plane, and deviations of every curve also reveal that off-axis light of different heights are well controlled so the examples do improve the spherical aberration, the astigmatic aberration and the distortion aberration. In addition, by observing the imaging quality data the distances amongst the three representing different wavelengths are pretty close to one another, which means the present invention is able to concentrate light of the three representing different wavelengths so that the aberration is greatly improved. Given the above, the present invention provides outstanding imaging quality by the above designs of each lens element as well as the excellent synergies gained from the combinations of lens elements.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. An optical imaging lens set, from an object side toward an image side in order along an optical axis, comprising: a first lens element, a second lens element, a third lens element, a fourth lens element and a fifth lens element, said first lens element to said fifth lens element each having an object-side surface facing toward said object side as well as an image-side surface facing toward said image side, wherein:

said first lens element has an image-side surface with a concave portion in a vicinity of its periphery and with a concave portion in a vicinity of said optical axis;

said second lens element is of a plastic material;

said third lens element has an object-side surface with a concave portion in a vicinity of said optical axis and an image-side surface with a concave portion in a vicinity of its periphery;

said fourth lens element has an object-side surface with a concave portion in a vicinity of said optical axis; and

said fifth lens element has an object-side surface with a concave portion in a vicinity of its periphery and an image-side surface with a convex portion in a vicinity of said optical axis, and the optical imaging lens set exclusively has five lens elements with refractive power, EFL is an effective focal length of said optical imaging lens set, said second lens element has a second lens element thickness T_2 along said optical axis and said fourth lens element has a fourth lens element thickness T_4 along said optical axis to satisfy $9.50 \leq EFL/(T_2+T_4)$.

2. The optical imaging lens set of claim **1**, wherein TTL is a distance from said first object-side surface of said first lens element to an image plane along said optical axis to satisfy $10.50 \leq TTL/T_2 \leq 22.80$.

3. The optical imaging lens set of claim **2**, wherein ALT is a total thickness of all five lens elements along said optical axis, an air gap G_{12} between said first lens element and said second lens element along said optical axis and an air gap G_{45} between said fourth lens element and said fifth lens element along said optical axis to satisfy$5.50 \leq ALT/(G_{12}+G_{45})$.

4. The optical imaging lens set of claim **1**, wherein ALT is a total thickness of all five lens elements along said optical axis to satisfy $6.50 \leq ALT/T_2$.

5. The optical imaging lens set of claim **4**, wherein TTL is a distance from said first object-side surface of said first lens element to an image plane along said optical axis, an air gap G_{12} between said first lens element and said second lens element along said optical axis, an air gap G_{23} between said second lens element and said third lens element along said optical axis and an air gap G_{45} between said fourth lens element and said fifth lens element along said optical axis to satisfy $4.20 \leq TTL/(G_{12}+G_{23}+G_{45})$.

6. The optical imaging lens set of claim **1**, wherein ALT is a total thickness of all five lens elements along said optical axis to satisfy $ALT/T_4 \leq 8.60$.

7. The optical imaging lens set of claim **6**, wherein TTL is a distance from said first object-side surface of said first lens element to an image plane along said optical axis, an air gap G_{23} between said second lens element and said third lens element along said optical axis and an air gap G_{45} between said fourth lens element and said fifth lens element along said optical axis to satisfy $4.20 \leq TTL/(G_{23}+G_{45}) \leq 8.50$.

8. The optical imaging lens set of claim **1**, wherein an air gap G_{12} between said first lens element and said second lens element along said optical axis and an air gap G_{23} between said second lens element and said third lens element along said optical axis to satisfy $EFL/(G_{12}+G_{23}) \leq 12.70$.

9. The optical imaging lens set of claim **8**, wherein TTL is a distance from said first object-side surface of said first lens element to an image plane along said optical axis and said fifth lens element has a fifth lens element thickness T_5 along said optical axis to satisfy $TTL/(T_4+T_5) \leq 6.50$.

10. The optical imaging lens set of claim **1**, wherein an air gap G_{23} between said second lens element and said third lens element along said optical axis and an air gap G_{45} between said fourth lens element and said fifth lens element along said optical axis to satisfy $EFL/(G_{23}+G_{45}) \leq 8.6$.

11. The optical imaging lens set of claim **10**, wherein ALT is a total thickness of all five lens elements along said optical axis and said third lens element has a third lens element thickness T_3 along said optical axis to satisfy $4.20 \leq ALT/(T_2+T_3)$.

12. The optical imaging lens set of claim **1**, wherein said first lens element has a first lens element thickness T_1 along said optical axis to satisfy $2.80 \leq (T_1+T_4)/T_2 \leq 4.50$.

13. The optical imaging lens set of claim **12**, wherein an air gap G_{12} between said first lens element and said second lens element along said optical axis, an air gap G_{23} between said second lens element and said third lens element along said optical axis and an air gap G_{45} between said fourth lens element and said fifth lens element along said optical axis to satisfy $EFL/(G_{12}+G_{23}+G_{45}) \leq 10.50$.

14. The optical imaging lens set of claim **1**, wherein ALT is a total thickness of all five lens elements along said optical axis and an air gap G_{34} between said third lens element and said fourth lens element along said optical axis to satisfy $1.3 \leq ALT/G_{34}$.

15. The optical imaging lens set of claim **14**, wherein said fifth lens element has a fifth lens element thickness T_5 along said optical axis to satisfy $8.50 \leq EFL/T_5 \leq 11.80$.

16. The optical imaging lens set of claim **1**, wherein an air gap G_{34} between said third lens element and said fourth lens element along said optical axis to satisfy $3.70 \leq EFL/G_{34} \leq 12.50$.

17. The optical imaging lens set of claim **16**, wherein TTL is a distance from said first object-side surface of said first lens element to an image plane along said optical axis, said first lens element has a first lens element thickness T_1 along said optical axis to satisfy $4.00 \leq TTL/(T_1+T_2)$.

18. The optical imaging lens set of claim **1**, wherein TTL is a distance from said first object-side surface of said first lens element to an image plane along said optical axis, an air gap G_{12} between said first lens element and said second lens element along said optical axis and an air gap G_{34} between said third lens element and said fourth lens element along said optical axis to satisfy $3.20 \leq TTL/(G_{12}+G_{34})$.

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(54) **MINIATURE TELEPHOTO LENS ASSEMBLY**

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(52) **U.S. Cl.**
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(58) **Field of Classification Search**
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USPC 359/714, 739, 740, 763, 764
See application file for complete search history.

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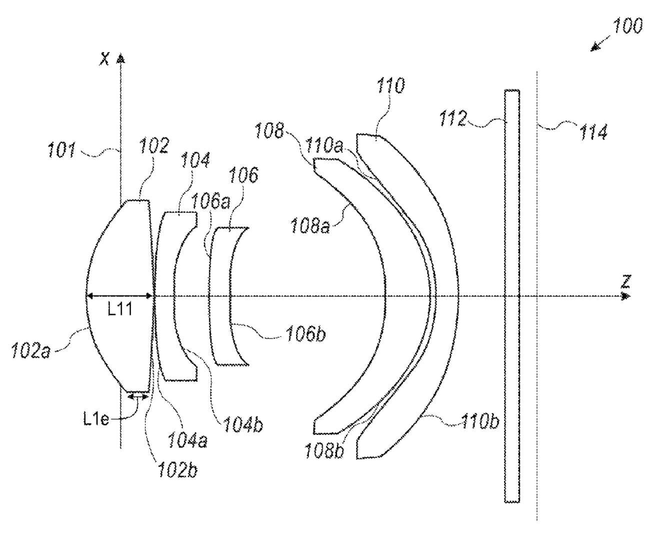
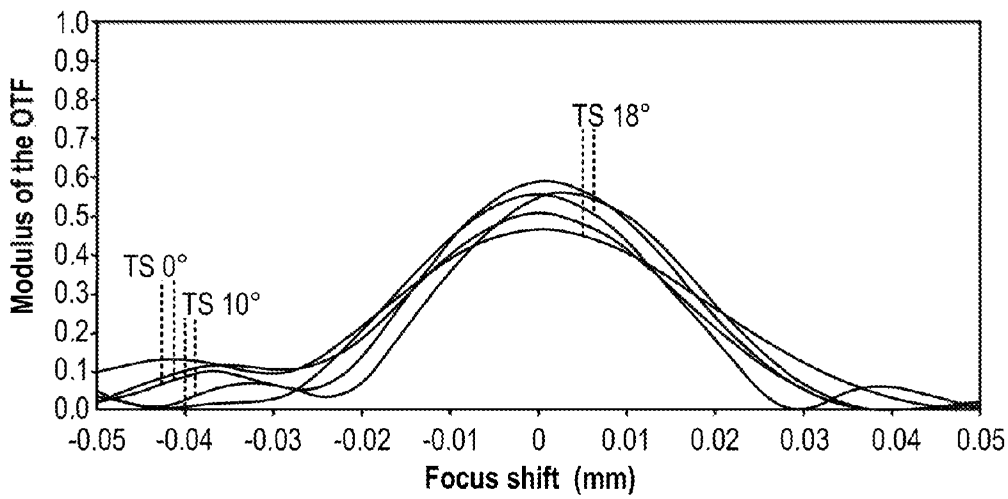
(57) **ABSTRACT**

An optical lens assembly includes five lens elements and provides a TTL/EFL<1.0. In an embodiment, the focal length of the first lens element f1<TTL/2, an air gap between first and second lens elements is smaller than half the second lens element thickness, an air gap between the third and fourth lens elements is greater than TTL/5 and an air gap between the fourth and fifth lens elements is smaller than about 1.5 times the fifth lens element thickness. All lens elements may be aspheric.

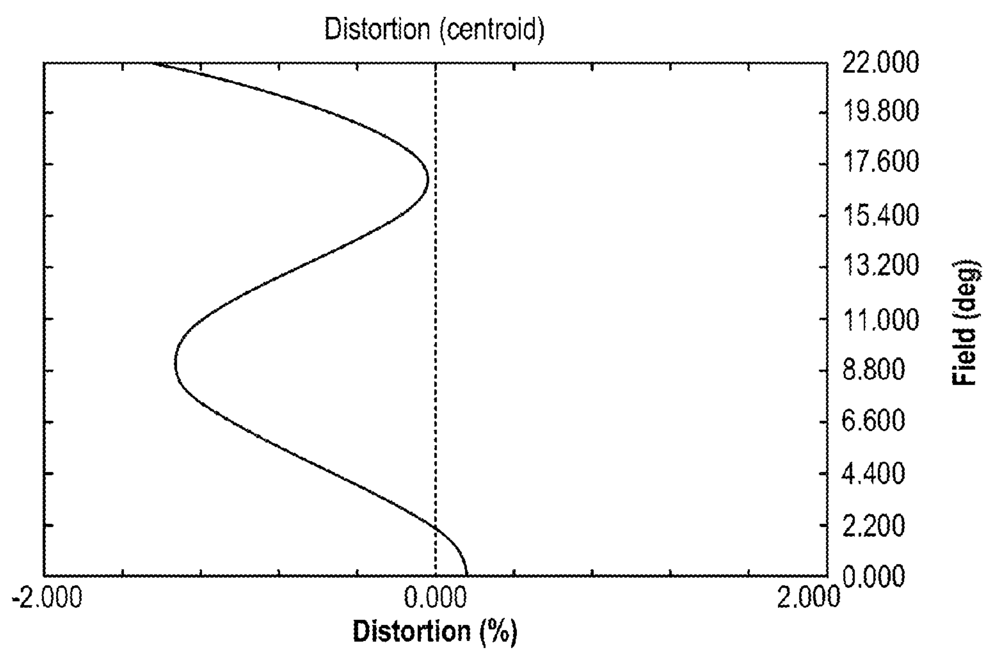
5 Claims, 6 Drawing Sheets





Polychromatic Diffraction Through Focus MTF
Angle 6/2/2013
Data for 0.4350 to 0.6560 µm.
Spatial Frequency: 180.0000 cycles/mm.

FIG. 2B



30/06/2013
Maximum distortion = 1.5%

FIG. 2C

UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE PATENT TRIAL AND APPEAL BOARD

- -

APPLE INC.,

Petitioner,

v.

IPR2018-01140
Patent No. 9,402,032

COREPHOTONICS, LTD.,

IPR2018-01146
Patent No. 9,568,712

Patent Owner.

- -

VIDEOTAPED DEPOSITION OF DUNCAN MOORE, PH.D.

June 7, 2019

Rochester, New York

Reported By:

MICHELLE MUNDT ROCHA

Job no: 25396

Page 118

DUNCAN MOORE, PH.D.
patent -- strike that.
You would agree with me that a person of ordinary skill in the art would be able to reduce an f-number to 2.5 -- strike that again.
You would agree with me that a person of ordinary skill in the art must have the knowledge to be able to reduce an f-number to 2.5 if the '712 patent isn't able to; correct?
MR. RUBIN: Objection, scope.
A. Well, for that one claim.
Q. For that one claim.
A. I mean, you'd have to -- that one claim says it's got to be smaller than 2.9.
Q. So a person of ordinary skill in the art for that claim would know how to reduce the f-number to 2.5?
MR. RUBIN: Objection, scope.
Q. Would you agree with that?
A. I assume so.
Q. And would you also agree that a person of ordinary skill in the art would understand how to reduce the f-number for Claim 2 to 1.7?
MR. RUBIN: Objection, scope.
A. I don't know whether you could get that

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DUNCAN MOORE, PH.D.
far down. 1.7 is a really fast f-number. I doubt that a five-element lens would work at f1.7.
Q. Would you agree with me that a person of ordinary skill in the art for Claim 2 would understand how to reduce the f-number to 2.2?
MR. RUBIN: Objection, scope.
A. I thought we were talking about Claim 6.
Q. Claim 6. I'm sorry. I'll re-ask the question. Thank you.
Would you agree with me that a person of ordinary skill in the art for Claim 6 would understand how to reduce the f-number to 2.2?
MR. RUBIN: Objection, scope.
A. I don't know how far down you could go. I just don't know. Without actually doing the design, I don't know if you could get to f2 or not. I don't have enough knowledge sitting here to do that.
Q. But a person of ordinary skill in the art would be able to reduce an f-number to under 2.9; correct?
A. Yes.
MR. MCDOLE: All right. Why don't we take a break.
(There was a discussion off the record.)

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DUNCAN MOORE, PH.D.
THE VIDEOGRAPHER: The time is 12:25. We're off the record.
(The proceeding recessed at 12:24 p.m.)
(The proceeding reconvened at 12:36 p.m.; appearances as before noted.)
THE VIDEOGRAPHER: The time is 12:37. We're back on the record.
DUNCAN MOORE, PH.D., resumes;
CONTINUING EXAMINATION BY MR. MCDOLE:
Q. Welcome back, Dr. Moore.
During the break did you have any conversations with Counsel about this deposition or the subject matter of the deposition?
A. Nope.
Q. Okay. If I can have you open back up the Konno reference, Apple Exhibit 1015. And if we can go back to page 21, we're looking at Table 1. Are you there?
A. Yes.
Q. In example 2 of Table 1 there is a column that says "LN2"; correct?
A. Yes.
Q. Can LN2 be a stand-alone lens assembly system?

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DUNCAN MOORE, PH.D.
A. Yes.
Q. Is it desirable in developing -- strike that.
Is it desirable in designing lens systems to reduce the f-number?
A. Depends on what the application is.
Q. If the application is cameras in smartphones, is it desirable to have a lower f-number?
A. It may be. It depends what you're trading off to get it. I mean, if you have to trade something else off to get it, maybe it's not such a good idea. But if you have sufficient light, there's no advantage of making a smaller f-number.
Q. But all else being equal, are smaller f-numbers better than larger f-numbers?
A. Only if the image performance remains the same.
Q. So if the image performance remains the same, it is desirable to have lower f-numbers; correct?
A. And you don't change the focal length and you don't change the field of view, you don't change anything else, then yes, your statement is true.
Q. And persons of ordinary skill in the art

US007321475B2

(12) **United States Patent**
Wang et al.

(10) **Patent No.: US 7,321,475 B2**
(45) **Date of Patent: *Jan. 22, 2008**

(54) **IMAGE PICK-UP LENS SYSTEM**

(75) Inventors: **Zhuo Wang**, Beijing (CN); **Min-Qiang Wang**, Beijing (CN); **Ying-Bai Yan**, Beijing (CN); **Guo-Fan Jin**, Beijing (CN); **Ji-Yong Zeng**, Beijing (CN)

(73) Assignees: **Tsing Hua University**, Beijing (CN); **Hon Hai Precision Industry Co., Ltd.**, Tu-Cheng, Taipei Hsien (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 48 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **10/954,726**

(22) Filed: **Sep. 30, 2004**

(65) **Prior Publication Data**

US 2005/0254147 A1 Nov. 17, 2005

(30) **Foreign Application Priority Data**

May 15, 2004 (CN) 2004 1 0027254

(51) **Int. Cl.**
G02B 9/04 (2006.01)
G02B 13/18 (2006.01)

(52) **U.S. Cl.** **359/793**; 359/717; 359/738

(58) **Field of Classification Search** 359/793–795, 359/738–740
See application file for complete search history.

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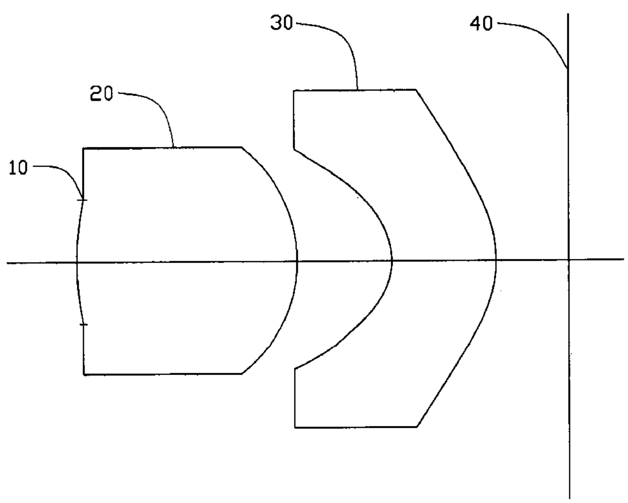
* cited by examiner

Primary Examiner—Jordan M. Schwartz
(74) *Attorney, Agent, or Firm*—Jeffrey T. Knapp

(57) **ABSTRACT**

An image pick-up lens system includes an aperture stop (**10**), a biconvex first lens (**20**), and a meniscus-shaped second lens (**30**) having a concave surface on a side of an object. The aperture stop, the first lens and the second lens are aligned in that order from the object side to an image side. Each of the lenses has at least one aspheric surface, and the following conditions are satisfied: (1) $0.5<f1/f<0.9$, and (2) $1<T/f<1.62$, wherein f1 is a focal length of the first lens, f is a focal length of the system, and T is a length from the aperture stop to an image pick-up surface of the image side.

6 Claims, 16 Drawing Sheets



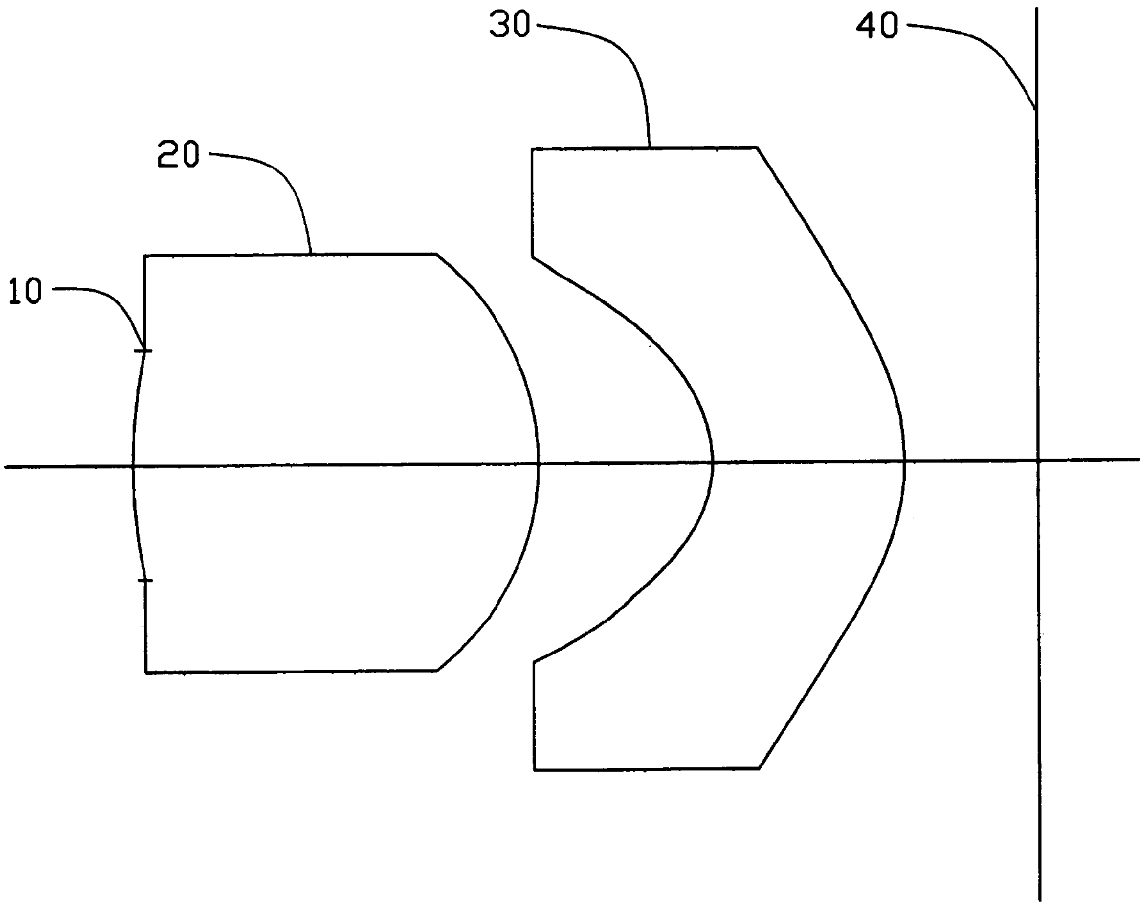


FIG. 1

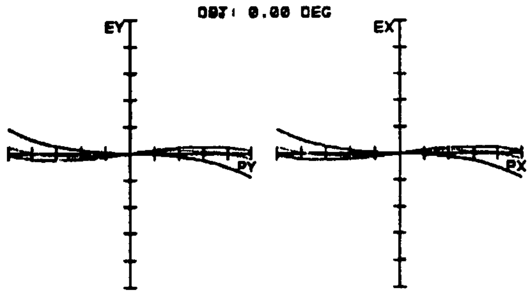


FIG. 2A

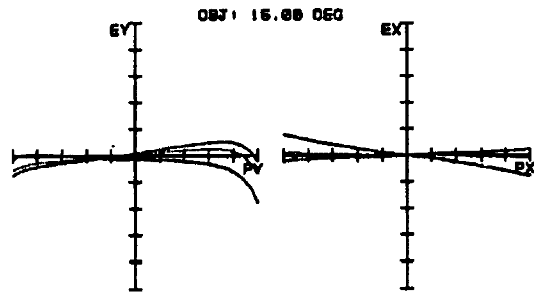


FIG. 2B

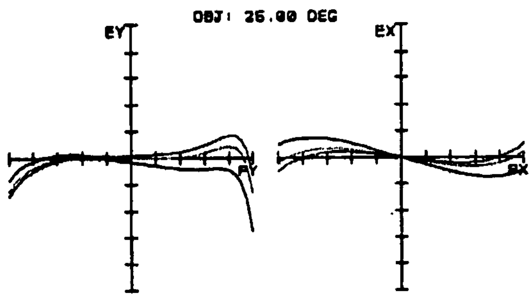


FIG. 2C

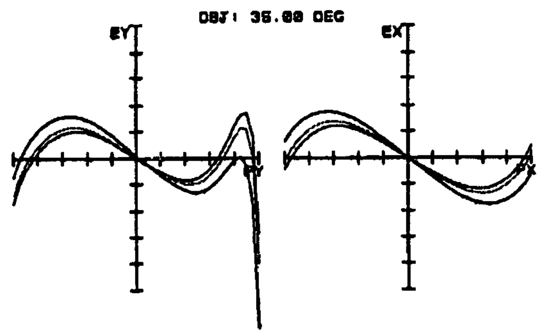


FIG. 2D

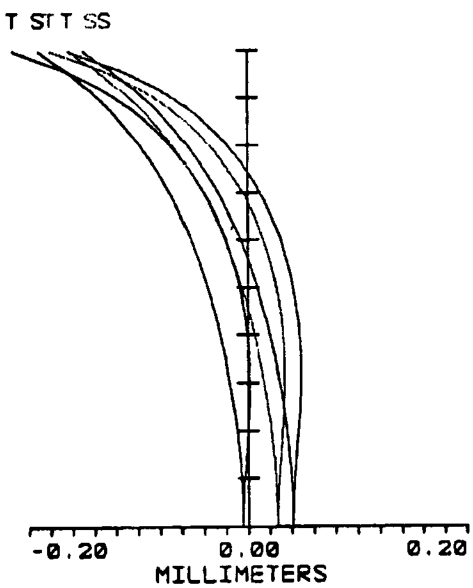


FIG. 3A

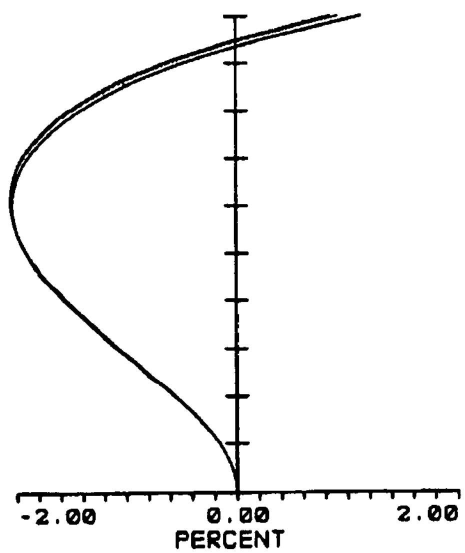


FIG. 3B

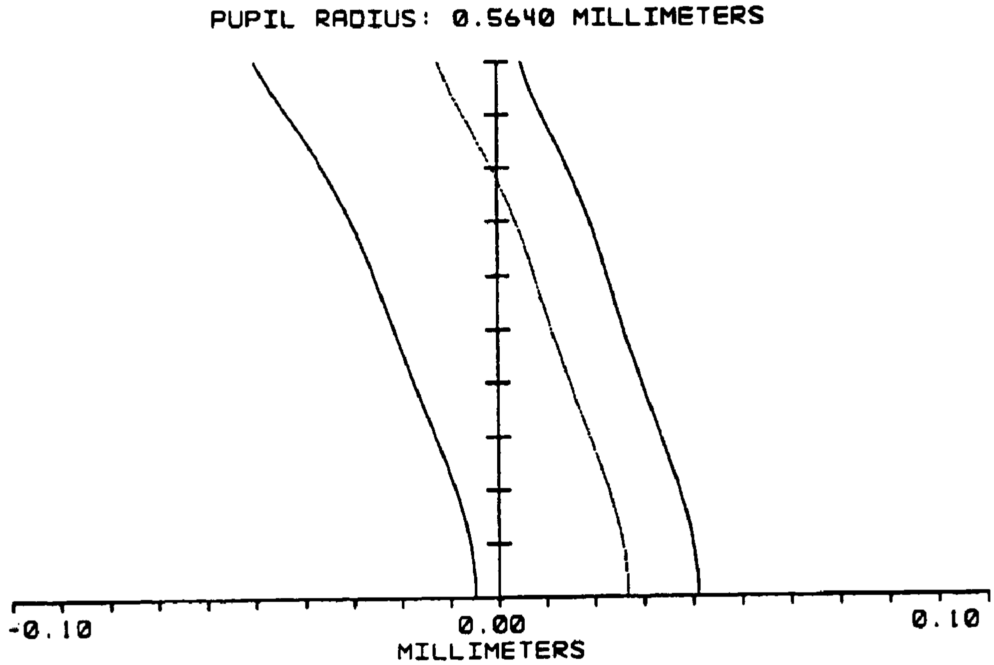

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FIG. 4

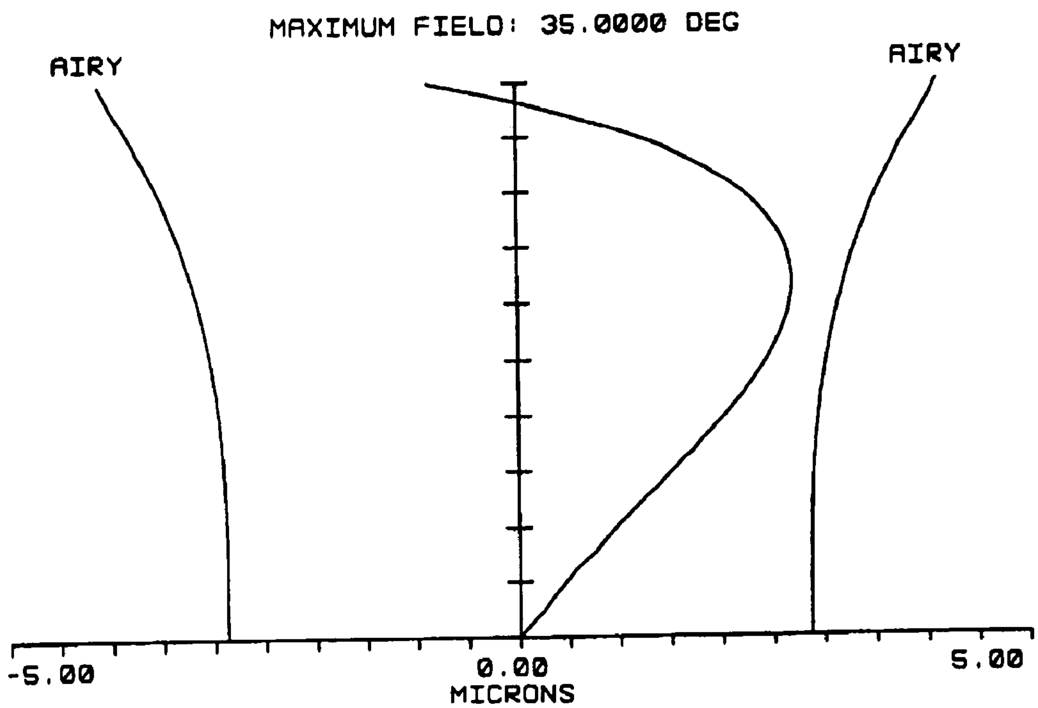
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FIG. 5

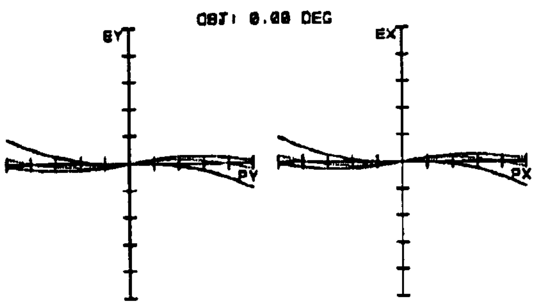

FIG. 6A

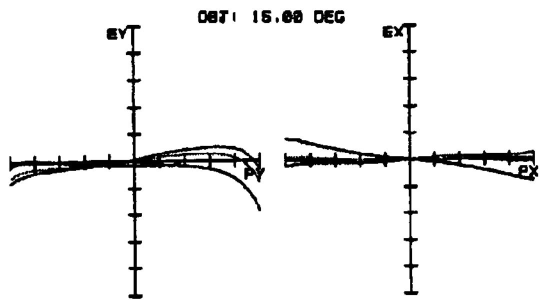

FIG. 6B

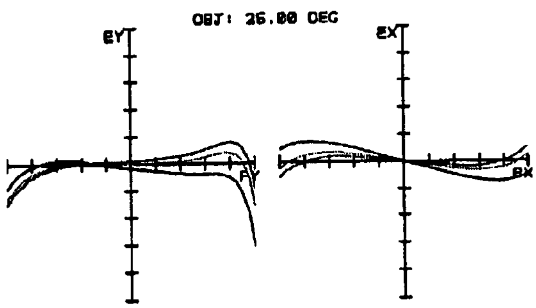

FIG. 6C

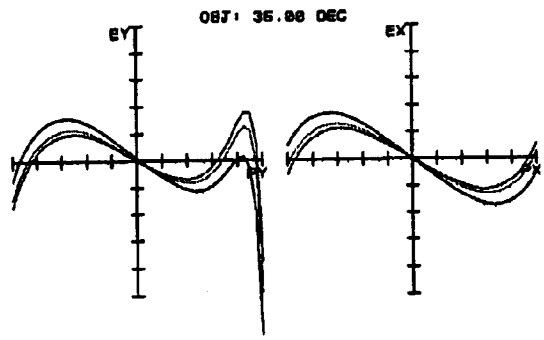

FIG. 6D

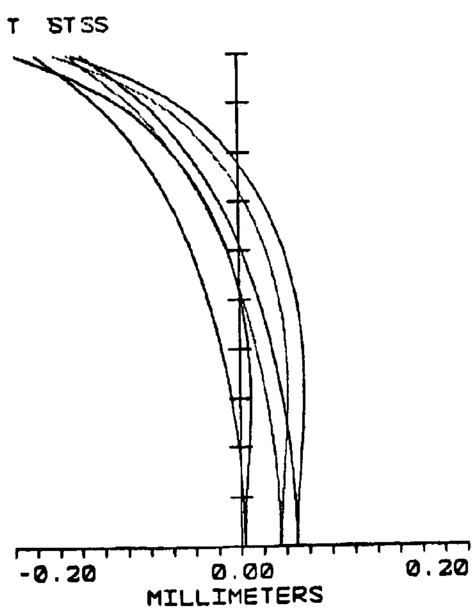

FIG. 7A

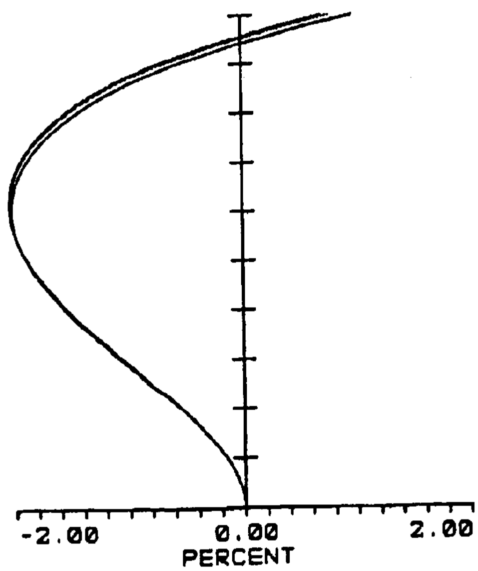

FIG. 7B

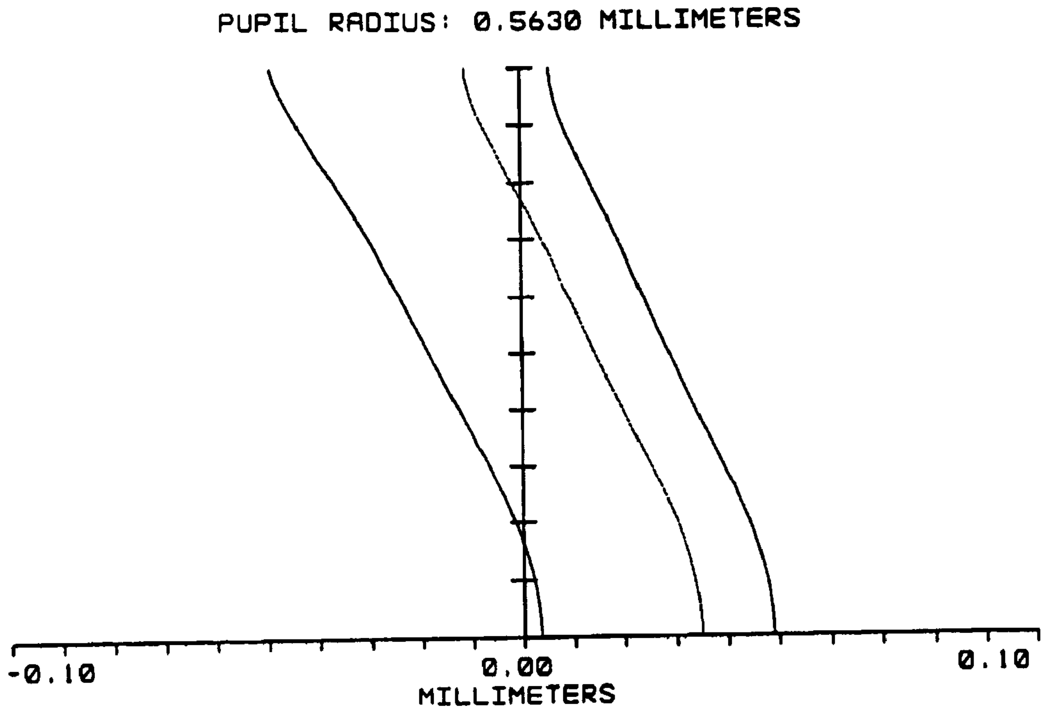
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FIG. 8

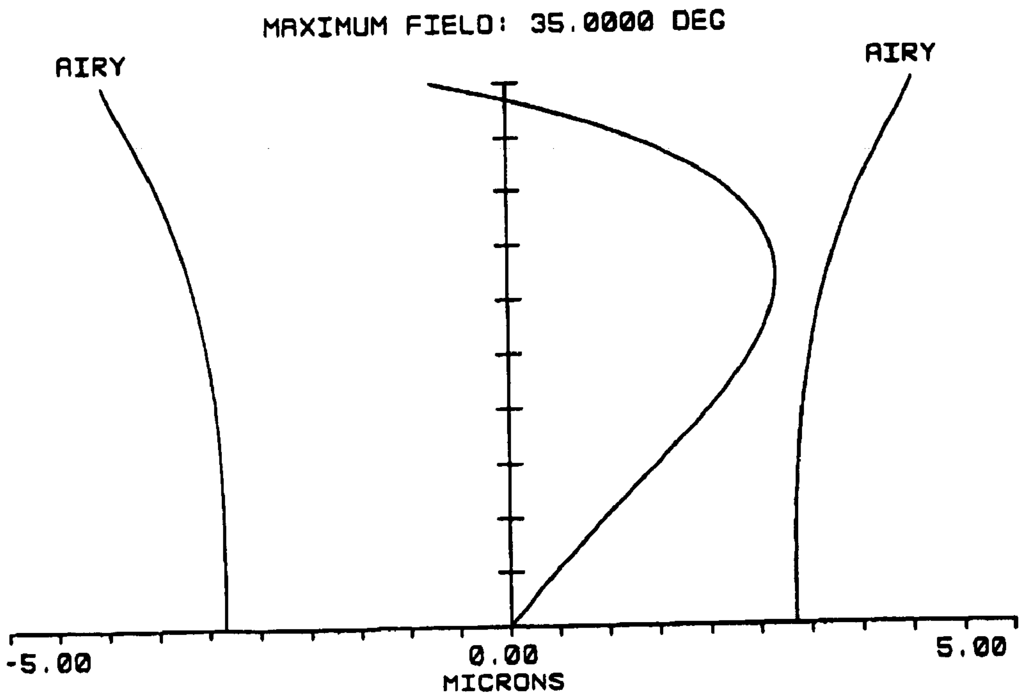
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FIG. 9

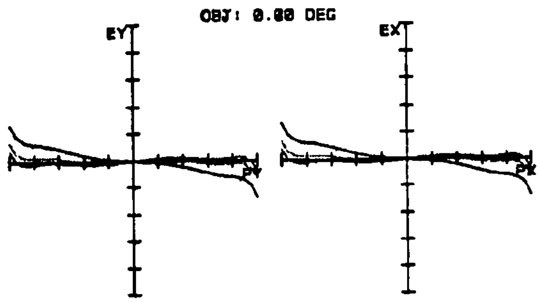

FIG. 10A

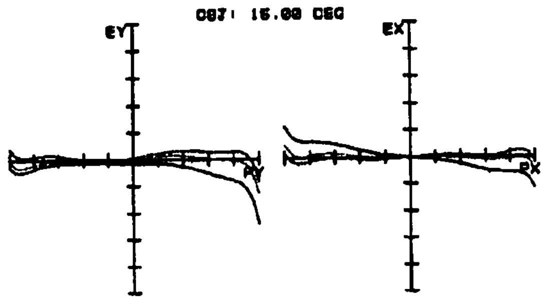

FIG. 10B

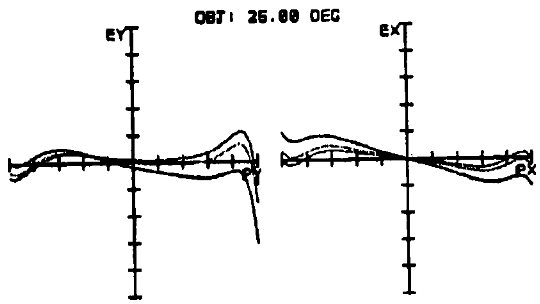

FIG. 10C

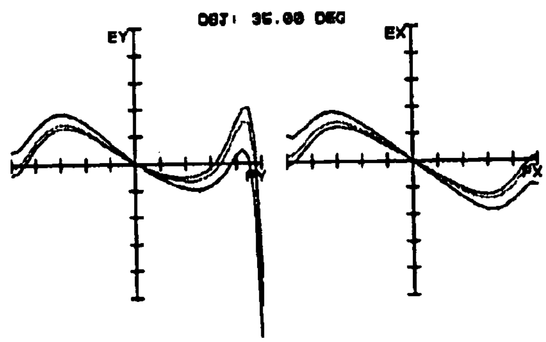

FIG. 10D

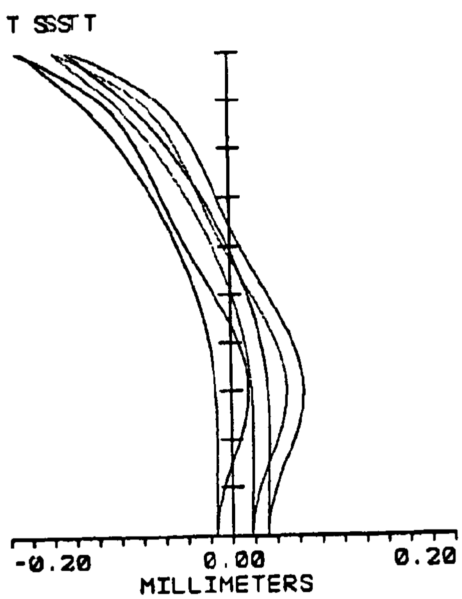

FIG. 11A

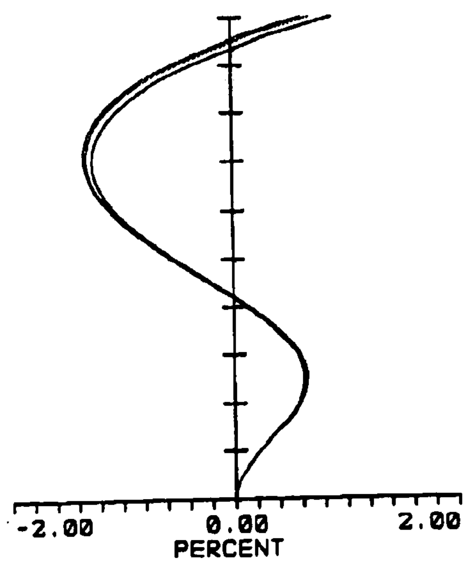

FIG. 11B

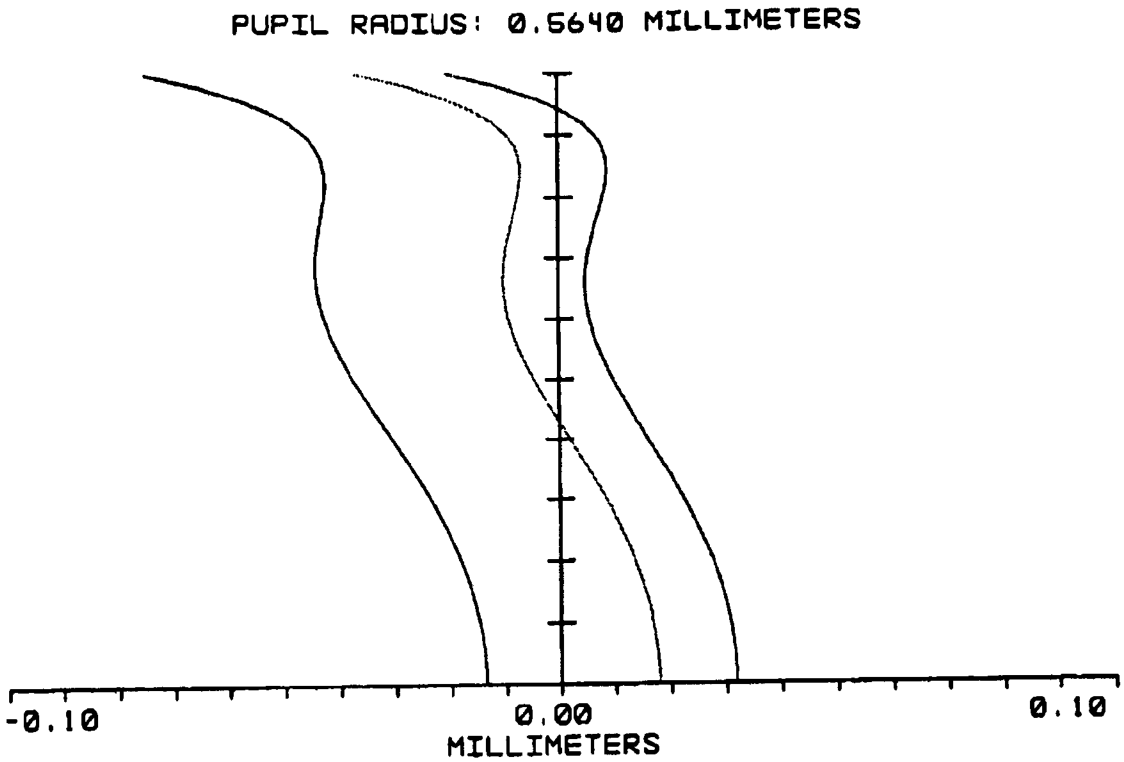
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FIG. 12

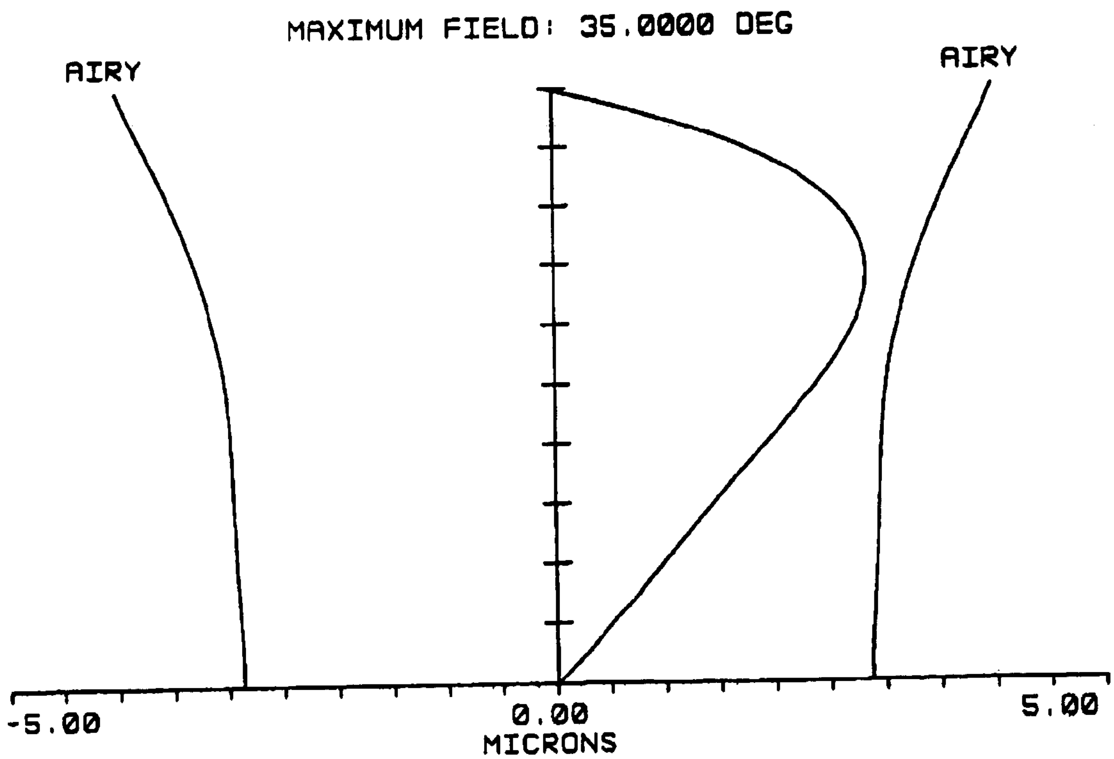
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FIG. 13

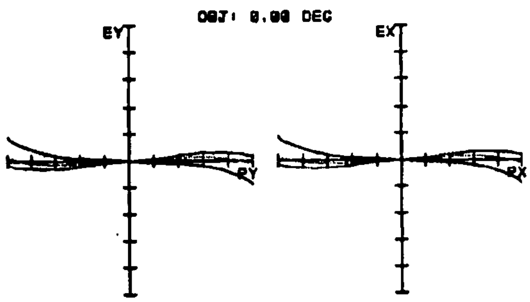

FIG. 14A

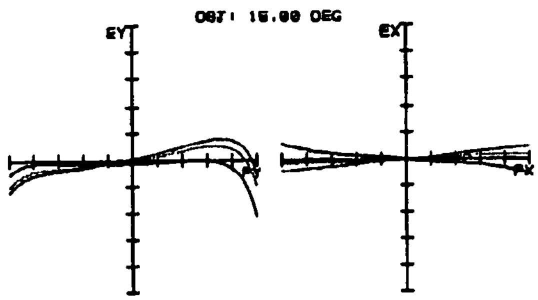

FIG. 14B

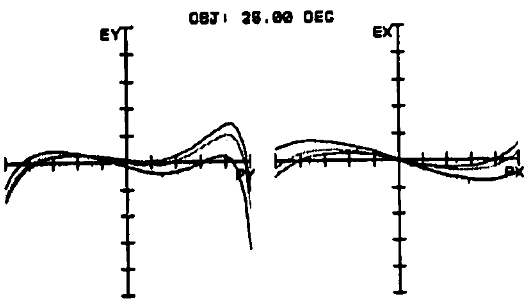

FIG. 14C

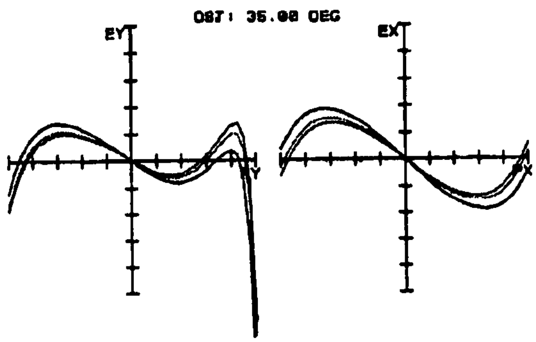

FIG. 14D

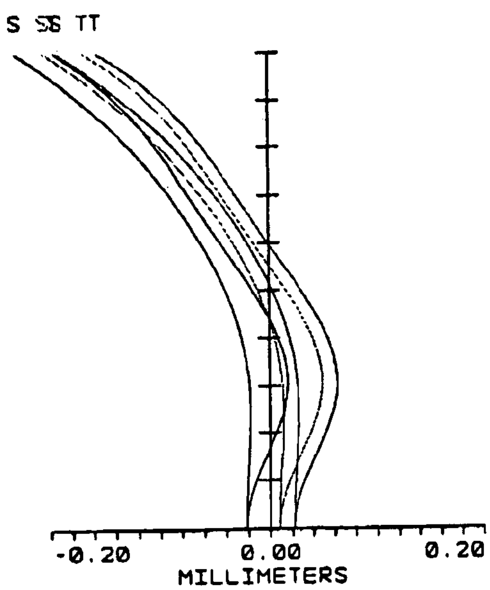

FIG. 15A

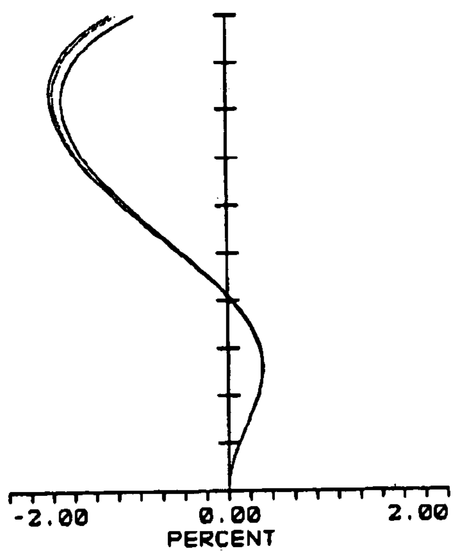

FIG. 15B

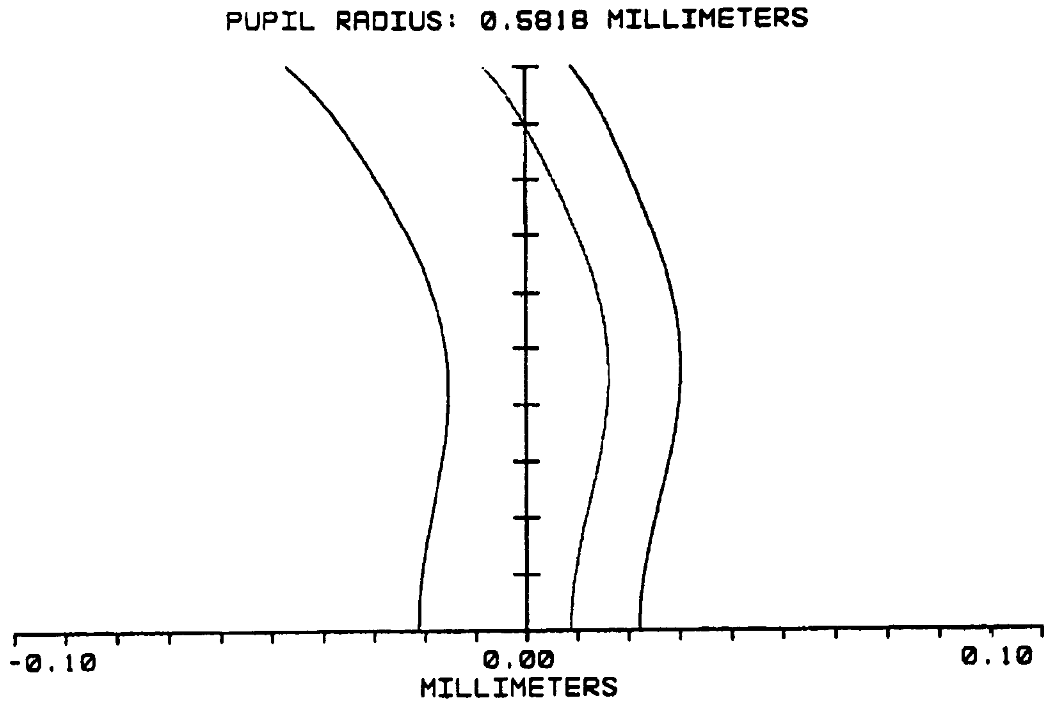
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FIG. 16

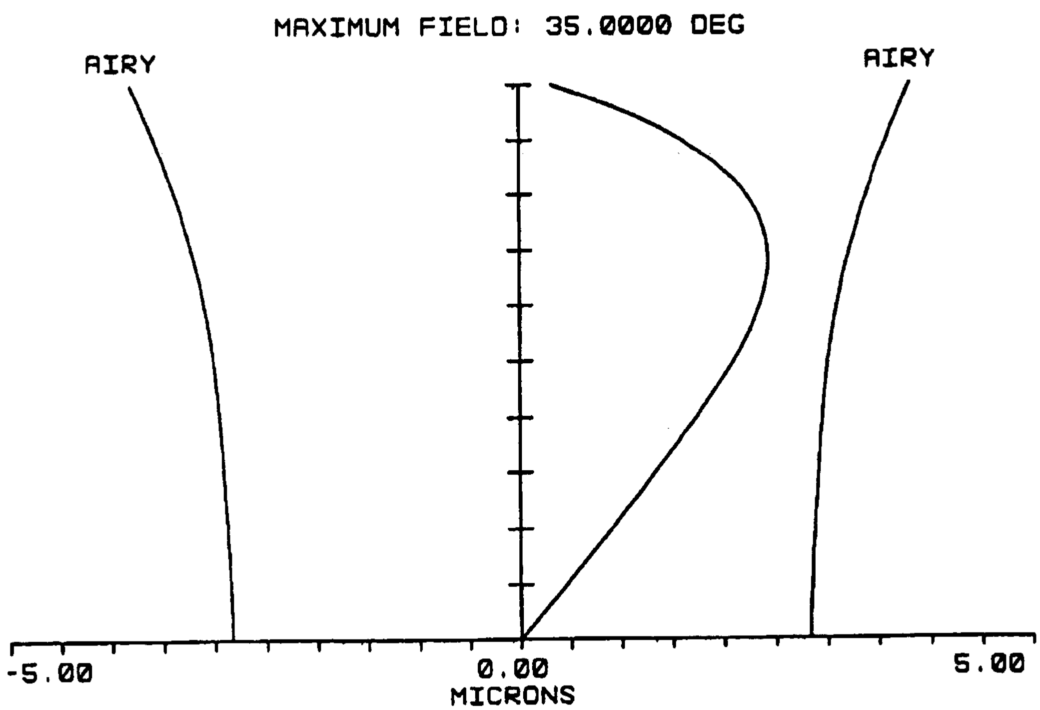
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FIG. 17

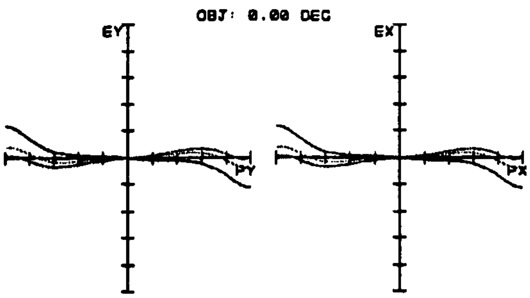

FIG. 18A

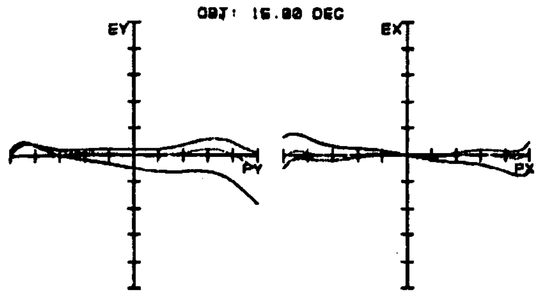

FIG. 18B

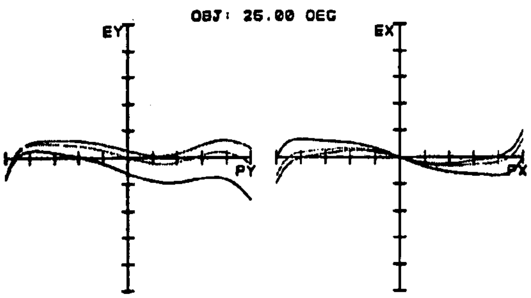

FIG. 18C

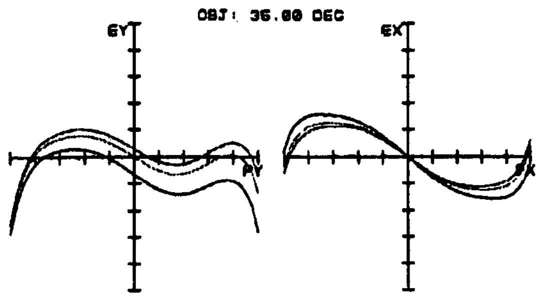

FIG. 18D

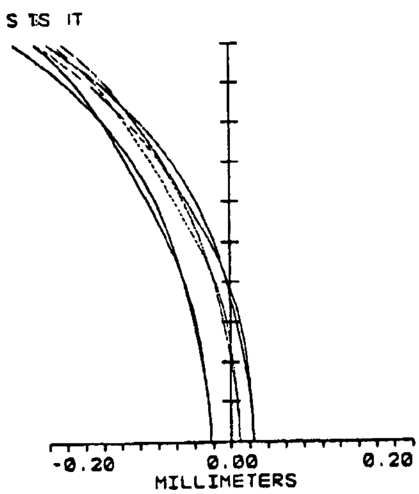

FIG. 19A

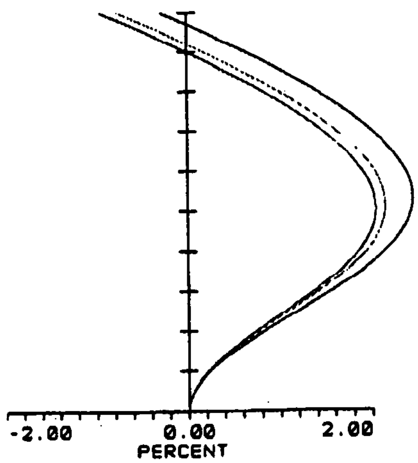

FIG. 19B

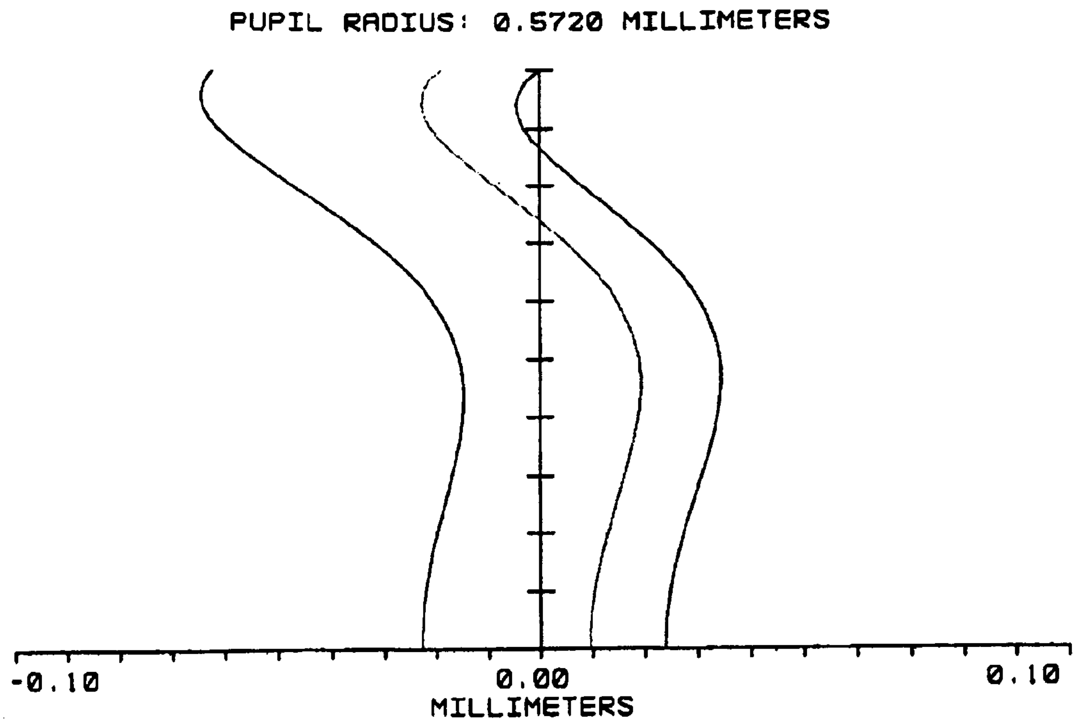
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FIG. 20

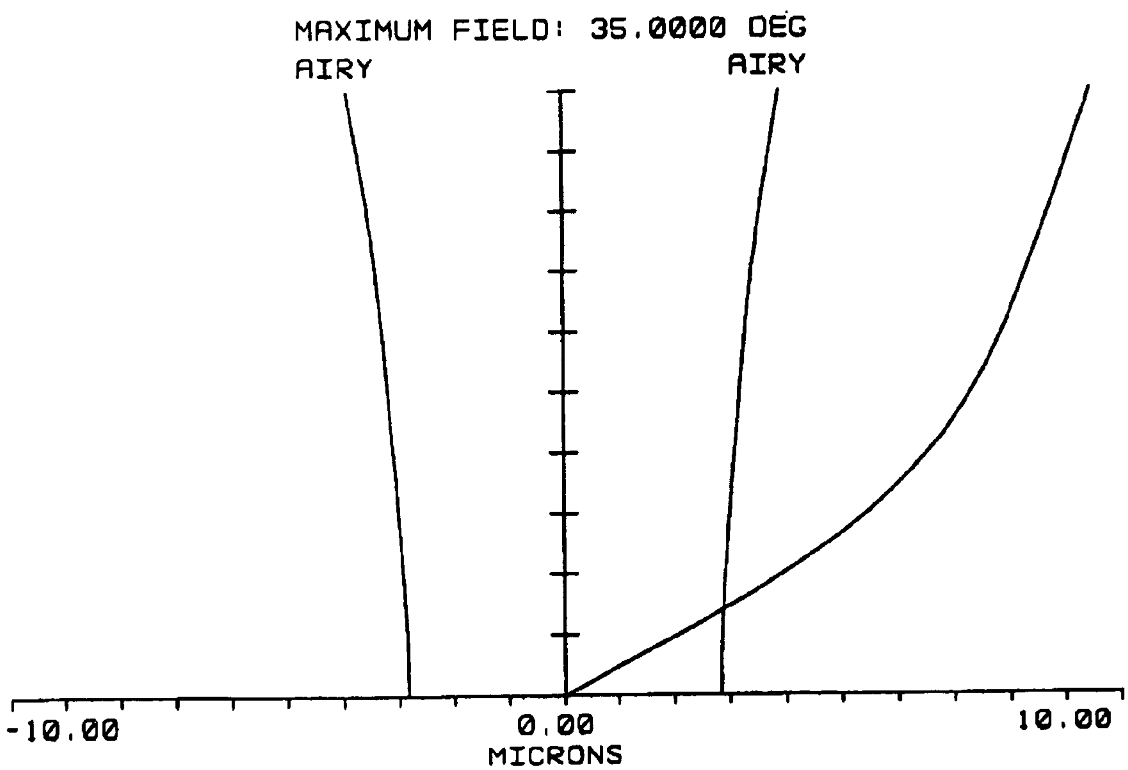
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FIG. 21

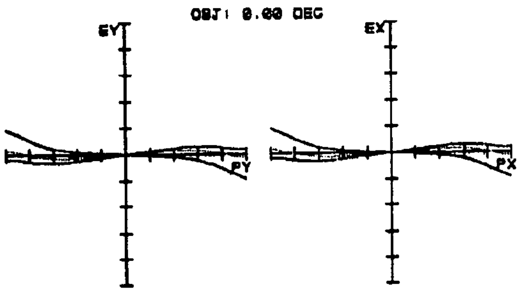

FIG. 22A

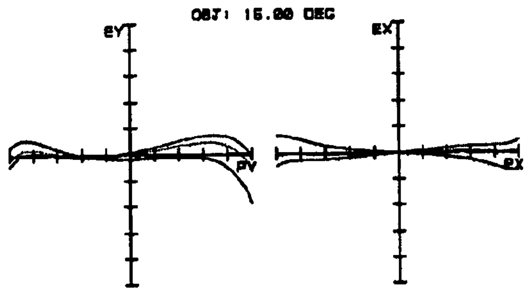

FIG. 22B

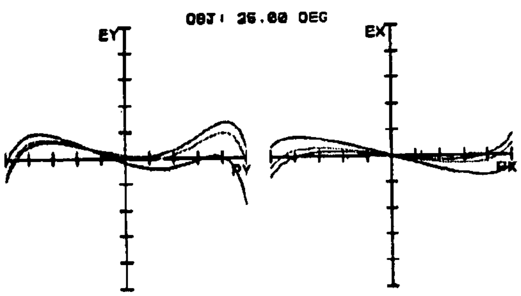

FIG. 22C

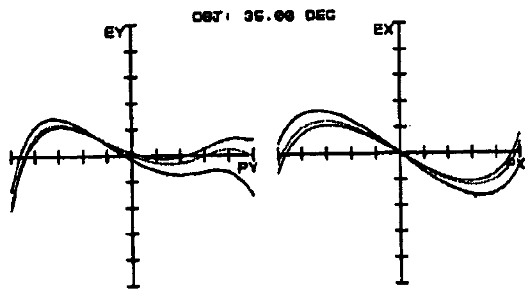

FIG. 22D

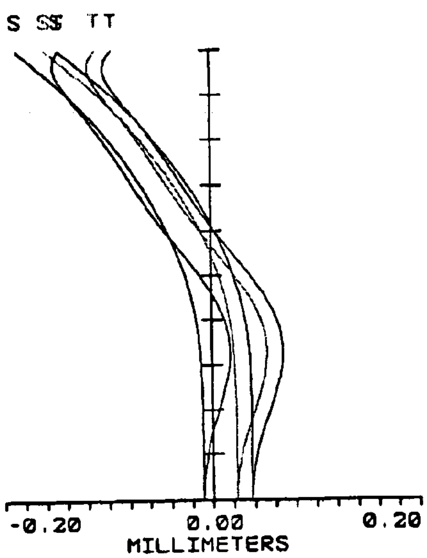

FIG. 23A

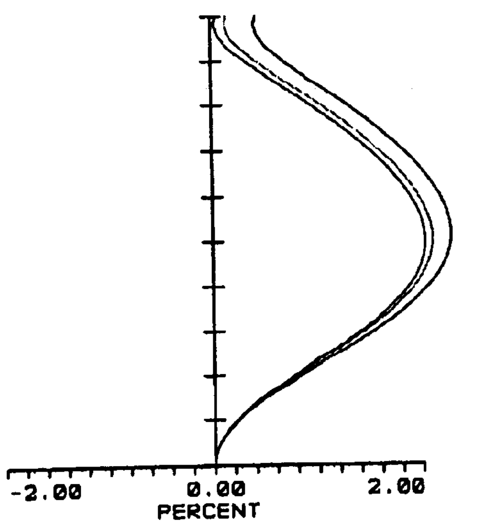

FIG. 23B

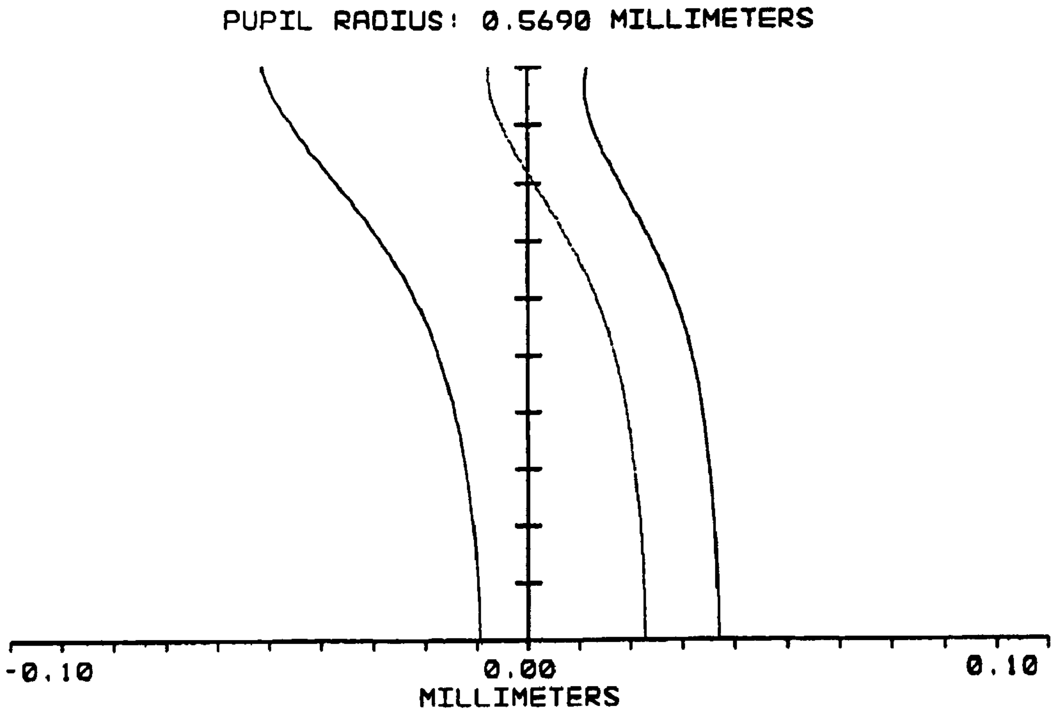
PUPIL RADIUS: 0.5690 MILLIMETERS
-0.10
0.00
0.10
MILLIMETERS

FIG. 24

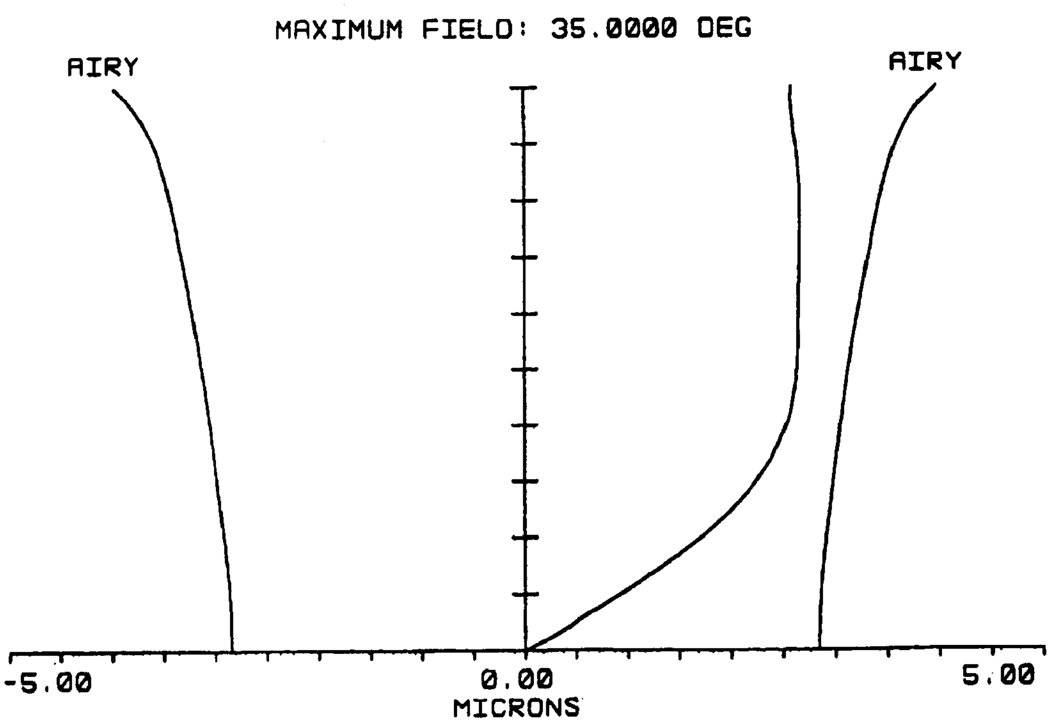
MAXIMUM FIELD: 35.0000 DEG
AIRY
AIRY
-5.00
0.00
5.00
MICRONS

FIG. 25

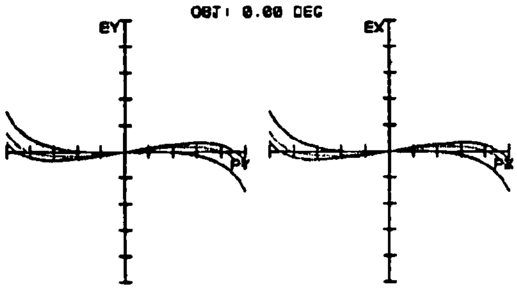

FIG. 26A

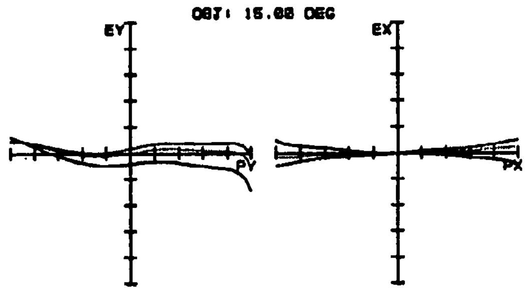

FIG. 26B

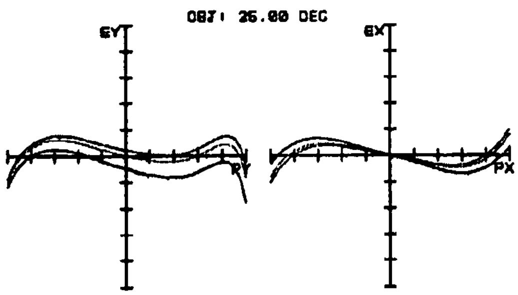

FIG. 26C

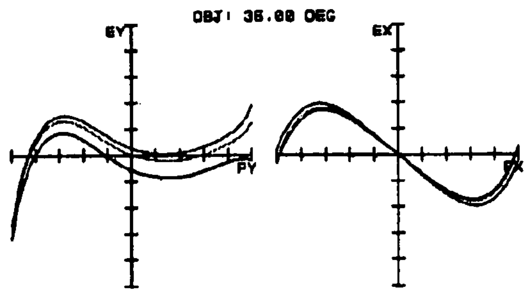

FIG. 26D

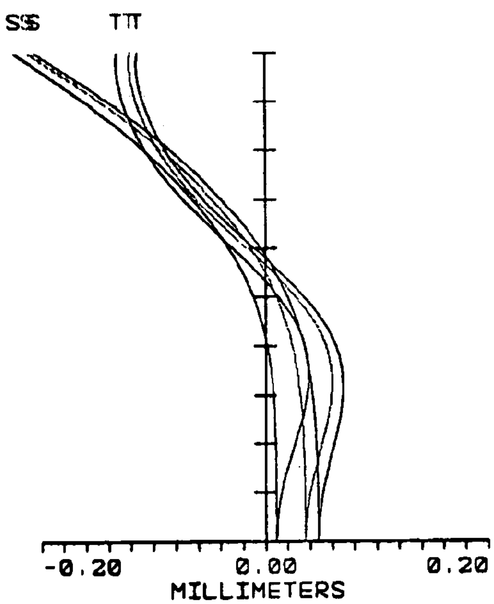

FIG. 27A

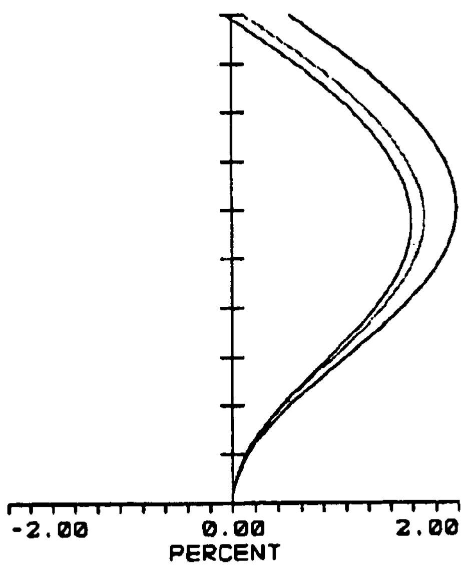

FIG. 27B

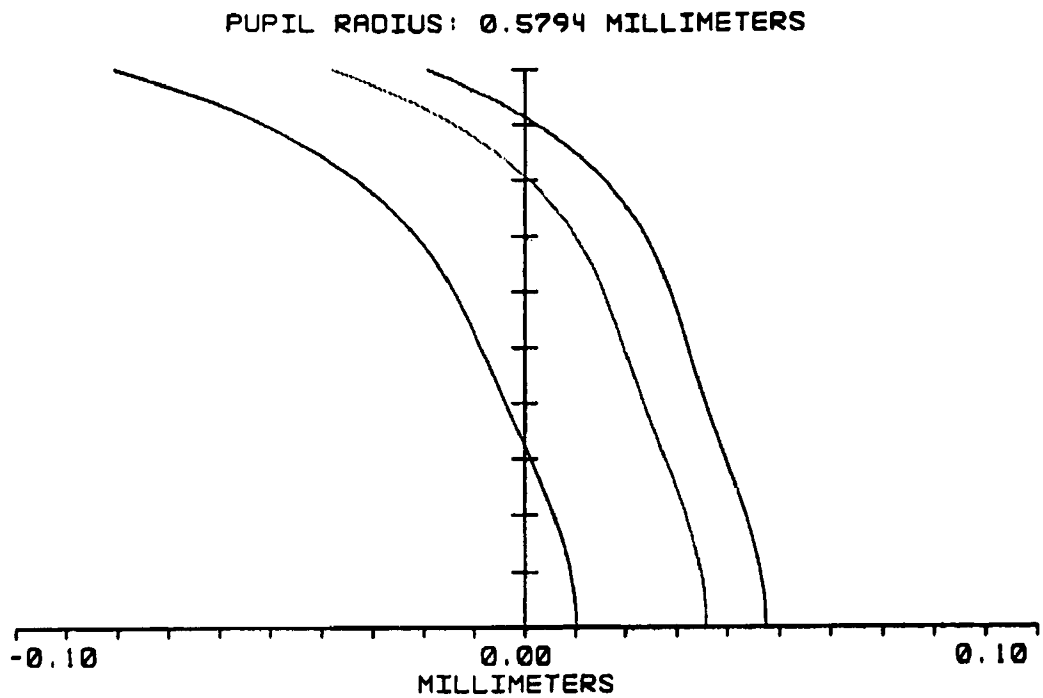
PUPIL RADIUS: 0.5794 MILLIMETERS
-0.10
0.00
0.10
MILLIMETERS

FIG. 28

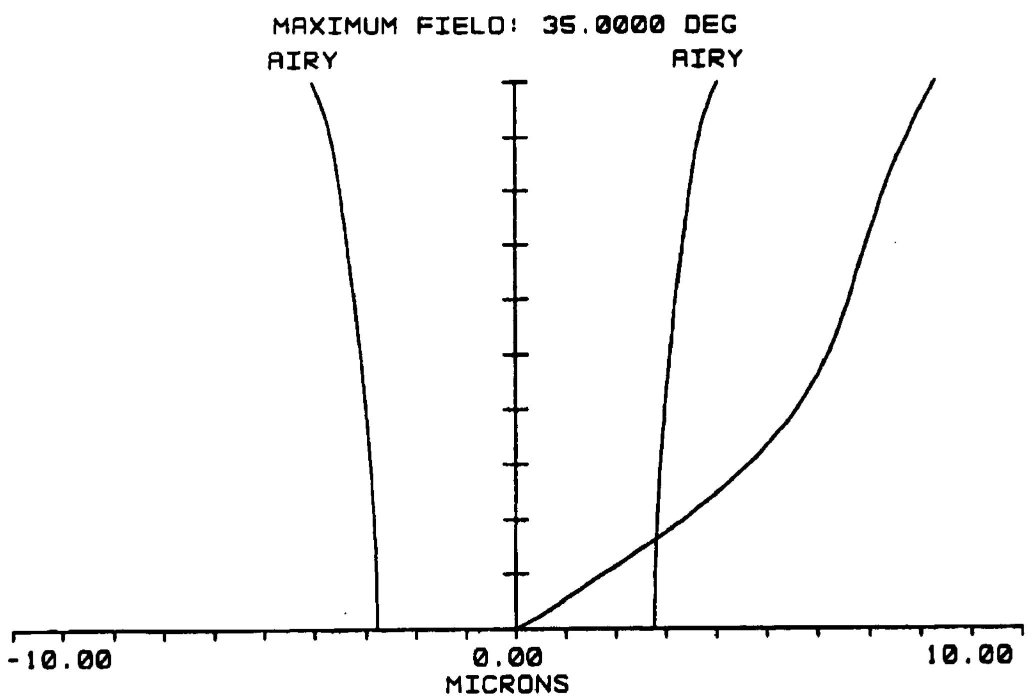
MAXIMUM FIELD: 35.0000 DEG
AIRY
AIRY
-10.00
0.00
10.00
MICRONS

FIG. 29

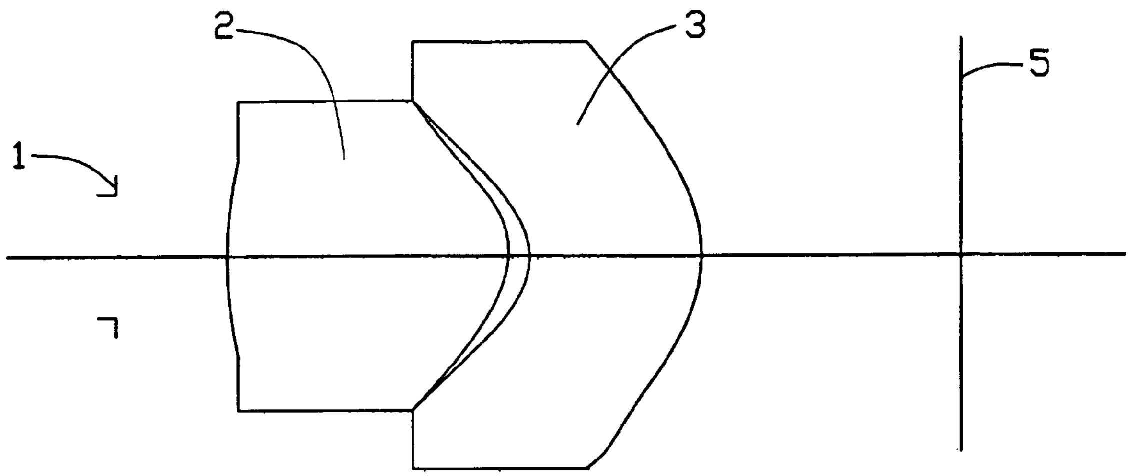

FIG. 30
(PRIOR ART)

IMAGE PICK-UP LENS SYSTEM

TECHNICAL FIELD

The present invention relates to an image pick-up lens system which projects an image of an object onto an image pick-up surface, the image pick-up lens system being suitable for use in products such as camera modules.

BACKGROUND

In recent years, camera modules for taking photos have begun to be incorporated in mobile terminals such as mobile phones and lap-top computers. Downsizing the camera modules is a prerequisite for enhancing the portability of these apparatuses. The camera module operates with an image pickup device such as a CCD (Charged Coupled Device) or a CMOS (Complementary Metal Oxide Semiconductor). Recently, a pixel having the size of approximately a few micrometers has become commercially feasible, and an image pickup device with high resolution and a compact size can now be commercialized. This is accelerating the demand for downsizing of image pick-up lens systems so that they are able to be suitably used with miniaturized image pick-up devices. It is also increasing expectations of cost reductions in image pick-up lens systems, commensurate with the lower costs enjoyed by modern image pickup devices. All in all, an image pick-up lens system needs to satisfy the oft-conflicting requirements of compactness, low cost, and excellent optical performance.

Compactness means in particular that a length from a lens edge of the lens system to an image pick-up surface should be as short as possible.

Low cost means in particular that the lens system should include as few lenses as possible; and that the lenses should be able to be formed from a resin or a plastic and be easily assembled.

Excellent optical performance can be classified into the following four main requirements:

First, a high brightness requirement, which means that the lens system should have a small F number (FNo.) Generally, the FNo. should be 2.8 or less.

Second, a wide angle requirement, which means that half of the field of view of the lens system should be 30° or more.

Third, a uniform illumination on the image surface requirement, which means that the lens system has few eclipses and/or narrows down an angle of incidence onto an image pick-up device.

Fourth, a high resolution requirement, which means that the lens system should appropriately correct fundamental aberrations such as spherical aberration, coma aberration, curvature of field, astigmatism, distortion, and chromatic aberration.

In a lens system which satisfies the low cost requirement, a single lens made from a resin or a plastic is desired. Typical such lens systems can be found in U.S. Pat. No. 6,297,915B1 and EP Pat. No. 1271215A2. However, even if the lens has two aspheric surfaces, it is difficult to achieve excellent optical performance, especially if a wide angle such as 70° is desired. Thus, the single lens system can generally only be used in a low-resolution image pick-up device such as a CMOS. In addition, a thick lens is generally used for correcting aberrations. Thus, a ratio of a total length of the lens system to a focal length of the lens (L/f) is about 2. In other words, it is difficult to make the lens system compact.

In a lens system which satisfies the excellent optical performance requirement, three lenses are desired. A typical such lens system can be found in U.S. Pat. No. 5,940,219. However, the ratio of a total length of the lens system to a total focal length of the three lenses (L/f) is about 2. It is difficult to make the lens system compact. In addition, the plurality of lenses increases costs.

In order to satisfy all the requirements of compactness, low cost and excellent optical performance, it is commonly believed that a two-lens system is desirable.

A well-known two-lens system is the retro-focus type lens system. A typical such lens system can be found in U.S. Pat. No. 6,449,105B1. The lens system comprises, from an object side to an image side, a first meniscus lens having negative refracting power and a convex surface on the object side, a stop, and a second meniscus lens having positive refracting power and a convex surface on the image side. The lens system helps correct wide angle aberrations. However, a shutter is positioned between the second lens and the image side, which adds to the distance between the second lens and the image side. Thus, the compactness of the lens system is limited.

U.S. Patent Publication No. 2004/0036983 discloses an image pick-up lens which overcomes the above described problems. As represented in FIG. **30** hereof, the image pick-up lens comprises, from an object side to an image side: an aperture stop **1**; a biconvex positive lens **2**; and a meniscus lens **3** having a concave surface on the object side. When each of the lenses **2**, **3** has at least one aspheric surface, the image pick-up lens satisfies the following conditions: $0.3<f1/f<0.9$ and $T/f<2.4$. In these expressions, "f" is an overall focal length of the lens system, "f1" is a focal length of the positive lens **2**, and "T" is a length from the aperture stop **1** to an image pick-up surface **5**.

However, the ratio of the total length of the lens system to the total focal length of the lenses **2**, **3** (L/f) is generally about 2. The smallest ratio obtainable is 1.7, which still constitutes a limitation on the compactness of the lens system. In addition, it is difficult to correct lateral chromatic aberration effectively, and thus the optical performance of the lens system is limited.

Therefore, a low-cost image pick-up lens system which can properly correct aberrations and has a compact configuration is desired.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide an image pick-up lens system which has a relatively short total length.

Another object of the present invention is to provide an image pick-up lens system which can optimally correct fundamental aberrations.

To achieve the above-described objects, an image pick-up lens system in accordance with the present invention comprises an aperture stop, a biconvex first lens, and a meniscus-shaped second lens having a concave surface on a side of an object. The aperture stop, the first lens and the second lens are aligned in that order from the object side to an image side. Each of the lenses has at least one aspheric surface. According to a first aspect, the following conditions are satisfied:

$$0.5<f1/f<0.9, \text{ and} \quad (1)$$

$$1<T/f<1.62, \quad (2)$$

wherein, f1 is a focal length of the first lens, f is a focal length of the system, and T is a length from the aperture stop to an image pick-up surface of the image side.

According to a second aspect, preferably, both a first surface on the object side and a second surface on the image side of the first lens are aspheric, and the following conditions are satisfied:

$$0.2<R2/R1<1, \text{ and} \tag{3}$$

$$1.2<d/R2<2.1, \tag{4}$$

wherein, R**1** is an absolute value of a radius of curvature of the first surface, R**2** is an absolute value of a radius of curvature of a second surface, and d is a thickness of the first lens.

Further, to correct field curvature, each of the first and second lenses is aspheric on both surfaces thereof, and the following condition is satisfied:

$$0.5<(1/R3)/(1/R1+1/R2+1/R4)<1, \tag{5}$$

wherein, R**3** is an absolute value of a radius of curvature of a third surface of the second lens on the object side, and R**4** is an absolute value of a radius of curvature of a fourth surface of the second lens on the image side.

Further still, the two lenses are made from a resin or a plastic. To correct chromatic aberration, the Abbe constant ν1 of the first lens and the Abbe constant ν2 of the second lens preferably satisfy the following condition:

$$\nu1-\nu2>20. \tag{6}$$

Because the first lens is positioned adjacent the aperture stop and has at least one aspheric surface, the image pick-up lens system can appropriately correct spherical and coma aberrations. In addition, because the second lens is positioned away from the aperture stop and has at least one aspheric surface, different chief rays of different field angle can have very different corresponding projection heights at the second lens. Therefore the system can appropriately correct astigmatism, field curvature and distortion, all of which are related to the field angle. Furthermore, the fourth surface of the second lens has a gradually varying refraction from a central portion thereof near an optical axis of the system to a peripheral edge portion thereof. Thus, a central portion of the second lens diverges light rays and a peripheral edge portion of the second lens converges light rays, so that the meridional/sagittal sections easily coincide. For all the above reasons, the optical image performance in wide angles of the system is enhanced. Moreover, because the first and second lenses can be made from a resin or a plastic, the system is relatively easy and inexpensive to mass manufacture.

Other objects, advantages and novel features of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of an image pick-up lens system in accordance with the present invention;

FIGS. **2-5** are graphs respectively showing transverse ray fan plots, field curvature and distortion, longitudinal spherical aberration, and lateral chromatic aberration curves for an image pick-up lens system in accordance with a first exemplary embodiment of the present invention;

FIGS. **6-9** are graphs respectively showing transverse ray fan plots, field curvature and distortion, longitudinal spherical aberration, and lateral chromatic aberration curves for an image pick-up lens system in accordance with a second exemplary embodiment of the present invention;

FIGS. **10-13** are graphs respectively showing transverse ray fan plots, field curvature and distortion, longitudinal spherical aberration, and lateral chromatic aberration curves for an image pick-up lens system in accordance with a third exemplary embodiment of the present invention;

FIGS. **14-17** are graphs respectively showing transverse ray fan plots, field curvature and distortion, longitudinal spherical aberration, and lateral chromatic aberration curves for an image pick-up lens system in accordance with a fourth exemplary embodiment of the present invention;

FIGS. **18-21** are graphs respectively showing transverse ray fan plots, field curvature and distortion, longitudinal spherical aberration, and lateral chromatic aberration curves for an image pick-up lens system in accordance with a fifth exemplary embodiment of the present invention;

FIGS. **22-25** are graphs respectively showing transverse ray fan plots, field curvature and distortion, longitudinal spherical aberration, and lateral chromatic aberration curves for an image pick-up lens system in accordance with a sixth exemplary embodiment of the present invention;

FIGS. **26-29** are graphs respectively showing transverse ray fan plots, field curvature and distortion, longitudinal spherical aberration, and lateral chromatic aberration curves for an image pick-up lens system in accordance with a seventh exemplary embodiment of the present invention; and

FIG. **30** is a schematic representation of an image pick-up lens in accordance with a prior publication.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

FIG. **1** shows a schematic configuration of an image pick-up lens system in accordance with the present invention. The system comprises an aperture stop **10**, a biconvex first lens **20**, and a meniscus-shaped second lens **30** having a concave surface on a side of an object. The aperture stop **10**, the first lens **20** and the second lens **30** are aligned in that order from the object side to an image side. The first and the second lenses **20**, **30** each have at least one aspheric surface. The first and second lenses **20**, **30** can be made from a resin or a plastic, which makes their manufacture relatively easy and inexpensive.

The aperture stop **10** is arranged closest to the object in order to narrow down an incident angle of chief rays onto an image pick-up surface **40** located at the image side. In addition, this arrangement of the aperture stop **10** helps shorten a total length of the system. For further cost reduction, the aperture stop **10** is preferably formed directly on a first surface (not labeled) of the first lens **20** on the object side. In practice, a portion of the first surface of the first lens **20** through which light rays are not transmitted is coated with a black material, which functions as the aperture stop **10**.

In order to provide compactness and excellent optical performance, the first and second lenses **20**, **30** satisfy the following conditions:

$$1<T/f<1.62, \text{ and} \quad (1)$$

$$(2)0.5<f1/f<0.9, \quad (2)$$

wherein, f1 is a focal length of the first lens **20**, f is a focal length of the system, and T is a length from the aperture stop **10** to the image pick-up surface **40**. The first condition (1) is for limiting the total length of the system. The second condition (2) is for correcting monochromatic aberrations, and providing both compactness and a desirable distribution of refracting power. In one aspect, when the ratio f1/f is above the lower limit of 0.5, the system provides satisfactory total refracting power and keeps high-order spherical aberration, high-order coma and lateral chromatic aberration of the system in a controlled range. In another aspect, when the ratio f1/f is below the upper limit of 0.9, the system is compact and provides satisfactory total refracting power.

The surfaces of the first and second lenses **20**, **30** are appropriately aspheric, which enables this small number of lenses to satisfy many if not all of the above-described requirements of compactness, low cost, and excellent optical performance.

In addition, preferably, both the first surface and a second surface (not labeled) of the first lens **20** on the image side are aspheric, and the following conditions are satisfied:

$$0.2<R2/R1<1, \text{ and} \quad (3)$$

$$1.2<d/R2<2.1, \quad (4)$$

wherein, R**1** is an absolute value of a radius of curvature of the first surface, R**2** is an absolute value of a radius of curvature of the second surface, and d is a thickness of the first lens **20**. The third condition (3) governs a distribution of refracting power for the first lens **20**, in order to correct monochromatic aberrations. The fourth condition (4) is for lessening an incident angle of the second surface of the first lens **20**, to further correct high-order aberrations.

The concave surface of the second lens **30** is defined as a third surface (not labeled). The first lens **20** and the second lens **30** satisfy the following condition:

$$0.5<(1/R3)/(1/R1+1/R2+1/R4)<1, \quad (5)$$

wherein, R**3** is an absolute value of a radius of curvature of the third surface of the second lens **30**, and R**4** is an absolute value of a radius of curvature of a fourth surface (not labeled) of the second lens **30** on the image side.

The fifth condition (5) is for correcting field curvature and obtaining a flat field. In one aspect, when the ratio (1/R**3**)/(1/R**1**+1/R**2**+1/R**4**) is above the lower limit of 0.5, the negative Petzval's Sum produced by the third surface of the second lens **30** can compensate the total positive Petzval's Sum produced by the first and second surfaces of the first lens **20** and the fourth surface of the second lens **30**. Thus, it is relatively easy to correct field curvature of the system. In another aspect, when the ratio (1/R**3**)/(1/R**1**+1/R**2**+1/R**4**) is below the upper limit of 1, the negative refracting power produced by the third surface of the second lens **30** can effectively compensate the positive coma and lateral chromatic aberration produced by the first lens **20**. Meanwhile, the radius of curvature R**3** of the third surface of the second lens **30** is not so small that increases the high-order aberrations of the system, and the negative refractive power provide by R**3** can correct the lateral chromatic aberration of Lens **20**. Furthermore, the radius of curvature R**3** of the third surface of the second lens **30** has the smallest absolute value among the four absolute values of radiuses of curvature R**1**, R**2**, R**3**, R**4** of the first and second lenses **20**, **30**. Thus in order to correct field curvature without producing high-order aberrations, the third surface of the second lens **30** is concave to the aperture stop **10**.

Also, in order to appropriately correct the chromatic aberration of the system, the Abbe constant ν1 of the first lens **20** and the Abbe constant ν2 of the second lens **30** preferably satisfy the following condition:

$$\nu 1-\nu 2>20. \quad (6)$$

Further, the fourth surface of the second lens **30** preferably has a gradually varying refraction from a central portion thereof near an optical axis of the system to a peripheral edge portion thereof. Thus, a central portion of the second lens **30** diverges light rays and a peripheral edge portion of the second lens **30** converges light rays, so that meridional/sagittal sections easily coincide. This feature further enhances the optical image performance in wide angles of the system.

The above explanations outline fundamental constituent features of the system of the present invention. Examples of the system will be described below with reference to FIGS. **2-29**. It is to be understood that the invention is not limited to these examples. The following are symbols used in each exemplary embodiment.

T: length from the aperture stop to the image pick-up surface
f: total length of the system
FNo: F number
ω: half field angle
2ω: field angle
R: radius of curvature
d: distance between surfaces on the optical axis of the system
Nd: refractive index of lens
ν: Abbe constant

In each example, the first and second surfaces of the first lens **20** and the third and fourth surfaces of the second lens **30** are aspheric. The shape of each aspheric surface is provided by expression 1 below. Expression 1 is based on a Cartesian coordinate system, with the vertex of the surface being the origin, and the optical axis extending from the vertex being the x-axis.

Expression 1:

$$x = \frac{ch^2}{1+\sqrt{1-(k+1)c^2h^2}} + \sum A_i h^i$$

wherein, h is a height from the optical axis to the surface, c is a vertex curvature, k is a conic constant, and A_i are i-th order correction coefficients of the aspheric surfaces.

EXAMPLE 1

Tables 1 and 2 show lens data of Example 1.

TABLE 1

f = 3.21 mm T = 4.00 mm FNo = 2.83 ω = 35°

Surface No.	R (mm)	D (mm)	Nd	ν	k
Stop 10	infinite	−0.08			0
1st surface	1.908685	1.949767	1.492	57.4	0.3969374
2nd surface	−1.386019	0.8410808			0.4322471
3rd surface	−0.6313817	0.9296156	1.585	29.9	−0.6737203
4th surface	−1.140475	0.2679967			−0.9677394

TABLE 2

	Surface No.			
	1st surface	2nd surface	3rd surface	4th surface
Aspherical coefficient	A2 = 0	A2 = 0	A2 = 0	A2 = 0
	A4 = −0.037981674	A4 = 0.040516016	A4 = −0.04769116	A4 = −0.0026459285
	A6 = −0.11117147	A6 = −0.0040262084	A6 = 0.05474841	A6 = 0.0088382976
	A8 = 0.25717755	A8 = −0.0022363842	A8 = 0.018494473	A8 = 0.0026971968
	A10 = −0.44540332	A10 = 0.0040769403	A10 = −0.0063129926	A10 = 0.00071976951
	A12 = 0.1964647	A12 = −0.0011660921	A12 = −0.002450423	A12 = −0.00036281554
	A14 = 0	A14 = 0	A14 = 0	A14 = 0
	A16 = 0	A16 = 0	A16 = 0	A16 = 0

FIGS. **2-5** are graphs of aberrations (transverse ray fan plots, field curvature/distortion, longitudinal spherical aberration, and lateral chromatic aberration) of the system of Example 1. FIGS. **2**A-**2**D respectively show aberration curves of meridional/sagittal sections in 0°, 15°, 25° and 35° field angles. FIGS. **3**A and **3**B respectively show field curvature and distortion curves. The first lens **20** is made from polymethyl methacrylate (PMMA), and the second lens **30** is made from a polycarbonate.

EXAMPLE 2

Lens data of Example 2 are shown in tables 3 and 4.

TABLE 3

f = 3.19 mm T = 3.99 mm FNo = 2.80 ω = 35°					
Surface No.	R (mm)	D (mm)	Nd	ν	k
Stop 10	infinite	−0.08			0
1st surface	1.895722	1.934008	1.492	57.4	−1.031395
2nd surface	−1.376186	0.8348153			0.441094
3rd surface	−0.6242678	0.9118045	1.585	29.9	−0.673748
4th surface	−1.126245	0.3122			−0.9667288

TABLE 4

	Surface No.			
	1st surface	2nd surface	3rd surface	4th surface
Aspherical coefficient	A2 = 0	A2 = 0	A2 = 0	A2 = 0
	A4 = −0.0086994569	A4 = 0.041163675	A4 = −0.048693006	A4 = −0.0027907875
	A6 = −0.1161784	A6 = −0.0042075403	A6 = 0.057214163	A6 = 0.0092363559
	A8 = 0.27353815	A8 = −0.002378654	A8 = 0.019671017	A8 = 0.0028687816
	A10 = −0.48215993	A10 = 0.0044133871	A10 = −0.0068339682	A10 = 0.00077916802
	A12 = 0.21645868	A12 = −0.0012847639	A12 = −0.0026997998	A12 = −0.00039973886
	A14 = 0	A14 = 0	A14 = 0	A14 = 0
	A16 = 0	A16 = 0	A16 = 0	A16 = 0

FIGS. **6-9** are graphs of aberrations (transverse ray fan plots, field curvature/distortion, longitudinal spherical aberration, and lateral chromatic aberration) of the system of Example 2. FIGS. **6**A-**6**D respectively show aberrations curves of meridional/sagittal sections in 0°, 15°, 25° and 35° field angles. FIGS. **7**A and **7**B respectively show field curvature and distortion curves. The first lens **20** is made from polymethyl methacrylate (PMMA), and the second lens **30** is made from a polycarbonate.

EXAMPLE 3

Lens data of Example 3 are shown in tables 5 and 6. In the lens data shown below, E shows powers of 10; that is, for example, 2.5E-0.3 means 2.5×10^{-3}.

TABLE 5

f = 3.21 mm T = 4.05 mm FNo = 2.83 ω = 35°					
Surface No.	R (mm)	D (mm)	Nd	ν	k
Stop 10	infinite	−0.0798			0
1st surface	1.937576	1.951123	1.492	57.4	−1.026366
2nd surface	−1.395695	0.842203			0.3649843
3rd surface	−0.6367427	0.9198735	1.585	29.9	−0.6782141
4th surface	−1.111585	0.3119658			−4.560295

TABLE 6

	Surface No.			
	1st surface	2nd surface	3rd surface	4th surface
Aspherical coefficient	A2 = 0	A2 = 0	A2 = 0	A2 = 0
	A4 = −0.0090154464	A4 = 0.047546265	A4 = −0.067457258	A4 = −0.17525752
	A6 = −0.027257396	A6 = −0.067428703	A6 = 0.048702325	A6 = 0.053841628
	A8 = −0.31450985	A8 = 0.088613357	A8 = −0.0016956663	A8 = 0.0007158852
	A10 = 0.60707428	A10 = −0.04786747	A10 = −8.414046E−005	A10 = −0.001238689
	A12 = 0	A12 = 0	A12 = 0	A12 = 0
	A14 = 0	A14 = 0	A14 = 0	A14 = 0
	A16 = 0	A16 = 0	A16 = 0	A16 = 0

FIGS. **10-13** are graphs of aberrations (transverse ray fan plots, field curvature/distortion, longitudinal spherical aberration, and lateral chromatic aberration) of the system of Example 3. FIGS. **10**A-**10**D respectively show aberrations curves of meridional/sagittal sections in 0°, 15°, 25° and 35° field angles. FIGS. **11**A and **11**B respectively show field curvature and distortion curves. The first lens **20** is made from polymethyl methacrylate (PMMA), and the second lens **30** is made from a polycarbonate.

EXAMPLE 4

Lens data of Example 4 are shown in tables 7 and 8. In the lens data shown below, E shows powers of 10.

TABLE 7

f = 3.26 mm T = 4.22 mm FNo = 2.80 ω = 35°					
Surface No.	R (mm)	D (mm)	Nd	ν	k
Stop 10	infinite	−0.067878			0
1st surface	2.124272	1.991005	1.492	57.4	−12.41067
2nd surface	−1.327932	0.7080908			−0.1739528
3rd surface	−0.6807691	0.6568542	1.585	29.9	−0.9940377
4th surface	−1.337036	0.861976			−3.860014

FIGS. **14-17** are graphs of aberrations (transverse ray fan plots, field curvature/distortion, longitudinal spherical aber

TABLE 8

	Surface No.			
	1st surface	2nd surface	3rd surface	4th surface
Aspherical coefficient	A2 = 0	A2 = 0	A2 = 0	A2 = 0
	A4 = 0.10925473	A4 = 0.011162728	A4 = −0.22040448	A4 = −0.14881856
	A6 = −0.13095248	A6 = −0.066705593	A6 = 0.019200829	A6 = 0.051775666
	A8 = 0	A8 = 0.068492417	A8 = −0.023114479	A8 = 0.0011871839
	A10 = 0	A10 = −0.04357828	A10 = −9.0582917E−005	A10 = −0.0013271067
	A12 = 0	A12 = 0	A12 = 0	A12 = 0
	A14 = 0	A14 = 0	A14 = 0	A14 = 0
	A16 = 0	A16 = 0	A16 = 0	A16 = 0

ration, and lateral chromatic aberration) of the system of Example 4. FIGS. **14**A-**14**D respectively show aberrations curves of meridional/sagittal sections in 0°, 15°, 25° and 35° field angles. FIGS. **15**A and **15**B respectively show field curvature and distortion curves. The first lens **20** is made from polymethyl methacrylate (PMMA), and the second lens **30** is made from a polycarbonate.

EXAMPLE 5

Lens data of Example 5 are shown in tables 9 and 10.

TABLE 9

f = 3.22 mm T = 4.99 mm FNo = 2.80 ω = 35°

Surface No.	R (mm)	D (mm)	Nd	ν	k
Stop 10	infinite	−0.03			0
1st surface	3.567241	2.042576	1.492	57.4	−0.9115067
2nd surface	−1.204826	0.8256124			−0.1979544
3rd surface	−0.5674448	0.8186415	1.585	29.9	−0.9227495
4th surface	−0.8538844				−1.068108

EXAMPLE 6

Lens data of Example 6 are shown in tables 11 and 12.

TABLE 11

f = 3.19 mm T = 4.32 mm FNo = 2.8 ω = 35°

Surface No.	R (mm)	D (mm)	Nd	ν	k
Stop 10	infinite	−0.05			0
1st surface	2.704951	1.934008	1.531	56.0	−19.70274
2nd surface	−1.264784	0.8348153			−0.3060202
3rd surface	−0.60228	0.9118045	1.585	29.9	−0.9132682
4th surface	−1.056885	0.640254			−2.01608

TABLE 10

	Surface No.			
	1st surface	2nd surface	3rd surface	4th surface
Aspherical coefficient	A2 = 0	A2 = 0	A2 = 0	A2 = 0
	A4 = −0.038187626	A4 = 0.046356766	A4 = 0.040616649	A4 = 0.0185752
	A6 = 0.025227628	A6 = −0.0032353324	A6 = 0.085273579	A6 = 0.0030064393
	A8 = 0.05774558	A8 = −0.0028835816	A8 = −0.079657862	A8 = 0.002911957
	A10 = −0.44540332	A10 = 0.0019185201	A10 = 0.050834821	A10 = 0.00065240269
	A12 = 0.1964647	A12 = 0.00024573464	A12 = −0.016829857	A12 = −0.00033965939
	A14 = 0	A14 = 0	A14 = 0	A14 = 0
	A16 = 0	A16 = 0	A16 = 0	A16 = 0

FIGS. **18-21** are graphs of aberrations (transverse ray fan plots, field curvature/distortion, longitudinal spherical aberration, and lateral chromatic aberration) of the system of Example 5. FIGS. **18**A-**18**D respectively show aberrations curves of meridional/sagittal sections in 0°, 15°, 25° and 35° field angles. FIGS. **19**A and **19**B respectively show field curvature and distortion curves. The first lens **20** is made from polymethyl methacrylate (PMMA), and the second lens **30** is made from a polycarbonate.

TABLE 12

	Surface No.			
	1st surface	2nd surface	3rd surface	4th surface
Aspherical coefficient	A2 = 0	A2 = 0	A2 = 0	A2 = 0
	A4 = 0.078640248	A4 = 0.043790817	A4 = 0.086709045	A4 = 0.028145024
	A6 = −0.1986909	A6 = −0.092545745	A6 = 0.049096719	A6 = −0.00012293722
	A8 = 0.27353815	A8 = 0.12998134	A8 = −0.10131265	A8 = −0.0034547048
	A10 = −0.48215993	A10 = −0.11896713	A10 = −0.14111931	A10 = −0.00054609844
	A12 = 0.21645868	A12 = 0.038733469	A12 = 0.13145728	A12 = 0.00054942201
	A14 = 0	A14 = 0	A14 = 0	A14 = 0
	A16 = 0	A16 = 0	A16 = 0	A16 = 0

FIGS. **22-25** are graphs of aberrations (transverse ray fan plots, field curvature/distortion, longitudinal spherical aberration, and lateral chromatic aberration) of the system of Example 6. FIGS. **22**A-**22**D respectively show aberrations curves of meridional/sagittal sections in 0°, 15°, 25° and 35° field angles. FIGS. **23**A and **23**B respectively show field curvature and distortion curves. The first lens **20** is made from a cyclo-olefin polymer, and the second lens **30** is made from a polycarbonate.

EXAMPLE 7

Lens data of Example 7 are shown in tables 13 and 14.

TABLE 13

f = 3.19 mm T = 5.12 mm FNo = 2.73 ω = 35°					
Surface No.	R (mm)	D (mm)	Nd	ν	k
Stop 10	infinite	−0.04			0
1st surface	3.73331	1.934008	1.531	56.0	7.649853
2nd surface	−0.9675068	0.3958819			−0.5408035
3rd surface	−0.5563445	0.9118045	1.585	29.9	−0.7896022
4th surface	−1.039531				−1.222231

TABLE 14

	Surface No.			
	1st surface	2nd surface	3rd surface	4th surface
Aspherical coefficient	A2 = 0	A2 = 0	A2 = 0	A2 = 0
	A4 = −0.036296997	A4 = 0.1129865	A4 = 0.31675922	A4 = 0.021944232
	A6 = −0.14080751	A6 = −0.084130154	A6 = 0.1861908	A6 = 0.0334663164
	A8 = 0.27353815	A8 = 0.12343708	A8 = −0.20723569	A8 = −0.0087931231
	A10 = −0.48215993	A10 = −0.11896713	A10 = 0.0707272	A10 = −0.002238773
	A12 = 0.21645868	A12 = 0.038733447	A12 = 0.032847897	A12 = 0.001090651
	A14 = 0	A14 = 0	A14 = 0	A14 = 0
	A16 = 0	A16 = 0	A16 = 0	A16 = 0

FIGS. **26-29** are graphs of aberrations (transverse ray fan plots, field curvature/distortion, longitudinal spherical aberration, and lateral chromatic aberration) of the system of Example 7. FIGS. **26**A-**26**D respectively show aberrations curves of meridional/sagittal sections in 0°, 15°, 25° and 35° field angles. FIGS. **27**A and **27**B respectively show field curvature and distortion curves. The first lens **20** is made from a cyclo-olefin polymer, and the second lens **30** is made from a polycarbonate.

Table 15 compares focal lengths and other parameters across Examples 1 through 7.

TABLE 15

	Example						
	1	2	3	4	5	6	7
FNo	2.83	2.8	2.83	2.8	2.8	2.8	2.73
2ω (°)	70	70	70	70	70	70	70
T (mm)	4	3.99	4.05	4.22	4.99	4.32	5.12
f (mm)	3.21	3.19	3.21	3.26	3.22	3.19	3.19
T/f	1.25	1.24	1.26	1.29	1.55	1.35	1.61
f1/f	0.63	0.63	0.62	0.63	0.66	0.61	0.53
R2/R1	0.73	0.73	0.72	0.62	0.34	0.47	0.26
d/R2	1.4	1.41	1.4	1.49	1.69	1.53	1.99

TABLE 15-continued

	Example						
	1	2	3	4	5	6	7
(1/R3)/(1/R1 + 1/R2 + 1/R4)	0.75	0.75	0.74	0.75	0.77	0.79	0.79
ν1-ν2	27.5	27.5	27.5	27.5	27.5	26.1	26.1

As seen in the above-described examples, the present invention provides a low-cost image pick-up lens system with a field angle of at least 70°. The total length of the system is small, and the system appropriately corrects fundamental aberrations.

It is to be understood that the invention may be embodied in other forms without departing from the spirit thereof. Thus, the described exemplary embodiments are to be considered in all respects as illustrative and not restrictive, and the invention is not to be limited to the details given herein.

What is claimed is:

1. An image pick-up lens system comprising:

an aperture stop;

a biconvex first lens; and

a meniscus-shaped second lens having a concave surface on a side of an object;

wherein the aperture stop, the first lens and the second lens are aligned in that order from the object side to an image side, the first lens is aspheric on both convex surfaces thereof, the second lens has at least one aspheric surface, and the following conditions are satisfied;

$$0.6<f1/f<0.7, \quad (1)$$

$$1<T/f<1.56, \quad (2)$$

$$0.45<R2/R1<1; \text{ and} \quad (3)$$

$$1.2<d/R2<2.1, \quad (4)$$

wherein f1 is a focal length of the first lens, f is a focal length of the system, T is a length from the aperture stop to an image pick-up surface of the image side, R**1** is an absolute value of a radius of curvature of the first lens on the object side, R**2** is an absolute value of a radius of curvature of the first lens on the image side, and d is a thickness of the first lens.

2. The image pick-up lens system in accordance with claim 1, wherein the second lens is aspheric on both surfaces and the following condition is satisfied;

$$0.5<(1/R3)/(1/R1+1/R2+1/R4)<1, \quad (5)$$

where R3 is an absolute value of a radius of curvature of the second lens on the object side, and R4 is an absolute value of a radius of curvature of the second lens on the image side.

3. The image pick-up lens system in accordance with claim 1, wherein the following condition is satisfied:

$$\nu1-\nu2<20, \quad (6)$$

where ν1 is the Abbe constant of the first lens, and ν2 is the Abbe constant of the second lens.

4. The image pick-up lens system in accordance with claim 1, wherein the first and second lenses are made from a resin or a plastic material respectively.

5. The image pick-up lens system in accordance with claim 4, wherein the first and second lenses are made from materials selected from polymethyl methacrylate, a polycarbonate, and a cyclo-olefin polymer.

6. The image pick-up lens system in accordance with claim 1, wherein the aperture stop is formed on the first lens.

* * * * *

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Date: November 3, 2020

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.,
Petitioner,

v.

COREPHOTONICS, LTD.,
Patent Owner.

Case IPR2020-00878
Patent 10,330,897 B2

Before BRYAN F. MOORE, MONICA S. ULLAGADDI, and JOHN R. KENNY, *Administrative Patent Judges.*

MOORE, *Administrative Patent Judge.*

DECISION
Granting Institution of *Inter Partes* Review
37 C.F.R. § 42.108

Paper No. 12

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.,
Petitioner,

v.

COREPHOTONICS, LTD.,
Patent Owner.

Case No. IPR2020-00878
U.S. Patent No. 10,330,897

PATENT OWNER'S RESPONSE

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TABLE OF AUTHORITIES

Cases

Statutes

PATENT OWNER'S EXHIBIT LIST

Exhibit No	*Description*
2001	Declaration of Tom D. Milster, Ph.D.
2002	Curriculum Vitae of Tom D. Milster, Ph.D.
2003	Deposition transcript of José Sasián, January 22, 2021
2004	José Sasián, Introduction to Lens Design (2019)
2005	Peter Clark, "Mobile platform optical design," Proc. SPIE 9293, International Optical Design Conference 2017, 92931M (17 December 2014)
2006	Symmons and Schaub, *Field Guide to Molded Optics* (2016)
2007	G. Beall, "By Design: Part design 106 – Corner radiuses," *Plastics Today* (199)
2008	*Handbook of Optics*, 2nd ed., vol. 2 (1995)
2009	Declaration of José Sasián in IPR2019-00030

I. INTRODUCTION

Patent Owner Corephotonics, Ltd. submits this response to the Petition (Paper 2) filed by Apple Inc., requesting *inter partes* review of U.S. Patent No. 10,330,897 (Ex. 1001, '897 patent). This response addresses Grounds 2–4 of this IPR, alleging that claims 2, 3, 5, 6, 8, 16, 18, 19, 21–24, and 30 of the '897 patent are obvious, based on modifications to lens designs found in Ogino (Ex. 1005) and in Chen (Ex. 1020). Corephotonics submits that the arguments presented herein and the additional evidence submitted, such as the testimony from Patent Owner's expert witness Dr. Tom Milster (Ex. 2001), along with the very references cited by Apple and textbook written by its expert, demonstrate that a POSITA would not have made the modifications to these lenses proposed by Apple. Apple has failed to establish obviousness of these challenged claims and that Apple's grounds 2–4 should be rejected.

II. SUMMARY OF ARGUMENT

Apple's obviousness arguments show that Dr. Sasián—a lens designer of exceptional ability who has taught lens design for decades and written textbooks on the subject—was able to, years after the effective filing date of Corephotonics' patent claims and with those patent claims in front of him, make

enough modifications to prior art lens designs that the results satisfy the challenged claims. The resulting lenses are presented with impressive-looking computer simulation results, purporting to show that at least on paper the lenses would be functional.

It could hardly be otherwise. Any valid patent claim must be enabled. It must be within the skill of even a journeyman designer to construct the claimed invention after reading the patent. It may be that a claim to a new chemical compound or protein sequence can be implemented using entirely routine chemistry or biology techniques once you have seen the claim. That does not make it obvious. As the Federal Circuit stated in *Belden*, establishing obviousness requires more than simply showing that a designer ***could have made*** specific changes to the prior art. It also requires showing that they ***would have been motivated to make*** those specific changes. Apple's obviousness arguments fail to meet this fundamental requirement of obviousness.

Apple's petition reflects a backwards approach to obviousness. Apple found an example in the prior art, Ogino Example 5, that it believed met all of the elements of the independent claims of the '897 patent. But it had a

problem: Ogino Example 5 clearly does not satisfy the limitations of numerous dependent claims. So, Apple asked: how would a designer who was motivated to satisfy the missing limitation have modified that design?

Motivation cannot be found in the challenged claims. It must be found in the prior art and the knowledge of a POSITA at the time. Would a POSITA have been motivated to change Ogino Example 5 in the ways proposed? The evidence emphatically says they would not.

For both grounds 2 and 3, Apple proposes a motivation to modify Ogino Example 5 to reduce its "f-number," either to a value cited in other prior art or to the value of another Ogino lens example. But this is not a well-reasoned motivation. Ogino Example 5 has by far the largest f-number of any example in Ogino. As Corephotonics' expert Dr. Milster explains and as common sense dictates, a POSITA who desired a lens with a small f-number would have chosen to start with an Ogino lens that already had a small f-number, indeed that already had the f-number values that Apple contends the POSITA would have been motivated to achieve. Apple provides no reasoned explanation that a POSITA would have chosen Ogino's lens with the ***largest*** f-number as a starting point to achieve a lens with a ***small*** f-number.

A POSITA might reasonably expect that there is a reason that Ogino Example 5 has a large f-number and that difficulties would be encountered if they tried to reduce it. Dr. Sasián's analysis shows that such fears would have been realized. As explained further below, reducing the f-number requires making the first lens in Ogino larger. Dr. Sasián's work shows that stretching Ogino's Example 5 to achieve the f-number Apple says a POSITA would have been motivated to achieve results in an unmanufacturable "paper lens," something that works as a computer simulation but cannot be built using practical means and would not work right even if it could be built.

A POSITA would have recognized that this modification to Ogino was unmanufacturable because it violates the rules of thumb and manufacturing tolerances set forth in two of the very prior art references that Apple relies on, Bareau and Beich, as well as in textbooks and references works by Dr. Sasián, Dr. Milster, and others. Whatever a POSITA would have been motivated to do to modify the Ogino lens, they would not have been motivated to use the impractical and unmanufacturable design proposed by Dr. Sasián for ground 2.

Apple proposed design for ground 3 suffers from some of the same problems. Once again, the purported motivation makes little rational sense. If the

goal was an f-number equal to the f-number in a different Ogino example, why wouldn't the POSITA simply use that other Ogino example? Apple provides no reasoned justification for starting with the largest f-number lens in Ogino if the goal was the f-number of the smallest f-number lens.

But more fundamentally, Apple and its expert provide no rationale for why Dr. Sasián modified the Ogino Example 5 lens in a particular way, or even ***how*** he did that modification. For example, an entire claim limitation—the "convex image-side surface" limitation of claims 8 and 24—required changing the sign of one of the parameters of the Ogino design. Making this change, from concave to convex, required disregarding one of the features that Ogino describes and claims as a defining characteristic of its invention: the meniscus shape of its first lens. Dr. Sasián cites to no prior art reference that suggests making this change from concave to convex, does not explain in his declaration the process that resulted in this change, and could not remember during his deposition how that change happened. At most, Apple's evidence on ground 3 goes to what a POSITA ***could have*** done, not what they ***would have been motivated*** to do.

Apple's arguments for ground 4 suffer from many of the same basic flaws as ground 2. The Chen patent does not disclose the ratio required by claims

16 and 30 or the lens diameter values that would allow one to calculate that ratio. So, Apple shows that a POSITA ***could have*** chosen a value that satisfied the claim limitation, in a "paper lens." As with ground 2, Dr. Sasián's ground 4 would not work in practice, based on the limits of manufacturability taught in the very prior art references Apple relies on, in Dr. Sasián textbook, and in other references discussed below. Further, as Dr. Milster shows, any practical implementation of the Chen lens, taking into account the limits of manufacturability, would not have satisfied the challenged claims. A POSITA would not have been motivated to implement Chen's lens design in the impractical, unmanufacturable way proposed by Apple. Indeed, the fact that the best arguments Apple was able to find, with the benefit of hindsight, depend on such unrealistic lens designs suggests that the inventions claimed in the '897 patent are, in fact, non-obvious.

For these reasons, and as explained further below, each of Apple's proposed modifications lacks the motivation that is legally required to establish obviousness, and each of Apple's obviousness grounds should be rejected.

III. OVERVIEW OF THE '897 PATENT

The '897 patent is concerned with designs for a "miniature telephoto lens assembly" of a kind suitable for use in mobile phones and other portable electronic products. (Ex. 1001, '897 patent at 1:26–30.) The example designs shown in the '897 patent utilize five plastic lens elements, each having a complex aspheric shape:

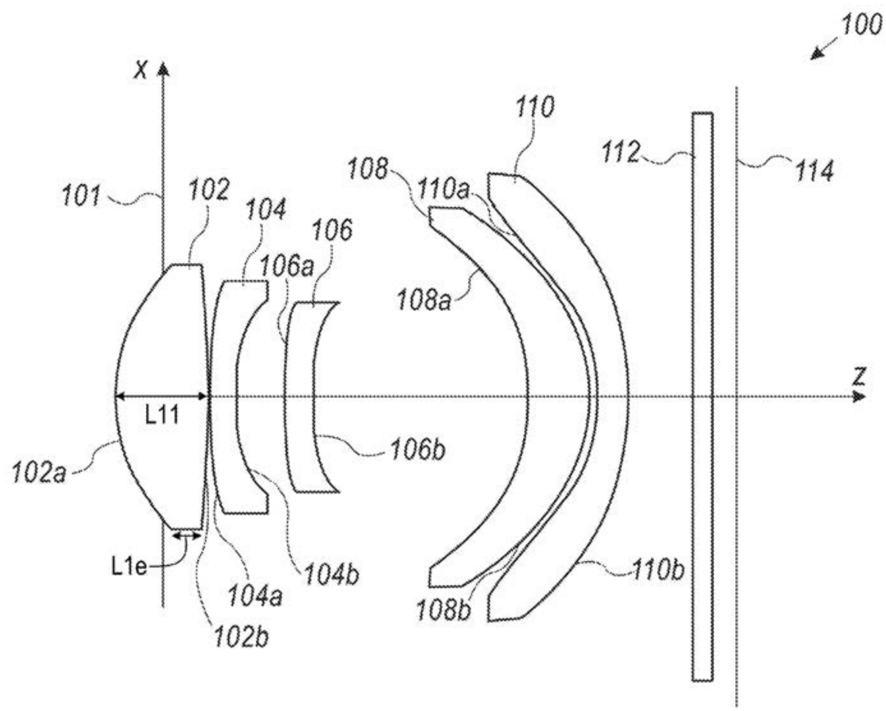


FIG. 1A

(Ex. 2001, Milster Decl., ¶ 36.)

The use of these multiple lens elements with aspheric shapes makes possible a lens that produces a high-quality image, by minimizing chromatic aberrations and other optical aberrations that would blur or distort the image. (Ex. 1001, ’897 patent at 2:22–34, 2:51–57; Ex. 2001, Milster Decl., ¶ 37.)

These multi-lens systems with aspheric lens surfaces have a vast range of possible designs. For example, the design in figure 1A from the ’897 patent requires several dozen numerical parameters to define the shapes, locations, and properties of its lens elements:

TABLE 1

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	−0.466		2.4
2	L11	1.5800	0.894	1.5345/57.095	2.5
3	L12	−11.2003	0.020		2.4
4	L21	33.8670	0.246	1.63549/23.91	2.2
5	L22	3.2281	0.449		1.9
6	L31	−12.2843	0.290	1.5345/57.095	1.9
7	L32	7.7138	2.020		1.8
8	L41	−2.3755	0.597	1.63549/23.91	3.3
9	L42	−1.8801	0.068		3.6
10	L51	−1.8100	0.293	1.5345/57.095	3.9
11	L52	−5.2768	0.617		4.3
12	Window	Infinite	0.210	1.5168/64.17	3.0
13		Infinite	0.200		3.0

TABLE 2

#	Conic coefficient k	α_2	α_3	α_4	α_5	α_6
2	−0.4668	7.9218E−03	2.3146E−02	−3.3436E−02	2.3650E−02	−9.2437E−03
3	−9.8525	2.0102E−02	2.0647E−04	7.4394E−03	−1.7529E−02	4.5206E−03
4	10.7569	−1.9248E−03	8.6003E−02	1.1676E−02	−4.0607E−02	1.3545E−02
5	1.4395	5.1029E−03	2.4578E−01	−1.7734E−01	2.9848E−01	−1.3320E−01
6	0.0000	2.1629E−01	4.0134E−02	1.3615E−02	2.5914E−03	−1.2292E−02
7	−9.8953	2.3297E−01	8.2917E−02	−1.2725E−01	1.5691E−01	−5.9624E−02
8	0.9938	−1.3522E−02	−7.0395E−03	1.4569E−02	−1.5336E−02	4.3707E−03
9	−6.8097	−1.0654E−01	1.2933E−02	2.9548E−04	−1.8317E−03	5.0111E−04
10	−7.3161	−1.8636E−01	8.3105E−02	−1.8632E−02	2.4012E−03	−1.2816E−04
11	0.0000	−1.1927E−01	7.0245E−02	−2.0735E−02	2.6418E−03	−1.1576E−04

(Ex. 1001, ’897 patent, col. 4; Ex. 2001, Milster Decl., ¶ 38.)

The ’897 patent provides examples of lens designs and their corresponding numerical parameters, and it also teaches and claims sets of conditions and relationships among the parameters that help to make a lens system with high performance characteristics. The resulting lens designs are thin and compact, appropriate for use in mobile devices, and they offer a large focal length (and thus a large degree of image magnification) for their physical size. (Ex. 1001, ’897 patent at 2:6–21; Ex. 2001, Milster Decl., ¶ 39.)

The lens designs in the ’897 patent are also manufacturable, meaning that they have shapes that can be successfully and repeatably manufactured using the techniques of plastic injection molding that are commonly used for mobile device camera lenses. The ’897 patent designs avoid features such as overly

narrow lens edges that make a lens difficult or impossible to manufacture. (Ex. 1001, ’897 patent at 2:35–50; Ex. 2001, Milster Decl., ¶ 40.)

One of the parameters of a lens design that is discussed in the ’897 patent and claimed in certain claims is the “f-number” or “F#.” As Dr. Milster explains, the f-number is a property of a lens that relates to how bright the image formed by the lens is. (*Id.*, ¶ 41.) A lens that forms brighter images is sometimes referred to as a “faster” lens, because for a given image sensor (or a given type of film) and focal length, the minimum amount of time required to capture an image varies inversely with the brightness of the image. (*Id.*) For a single thin lens, the f number is equal to the focal length of the lens divided by the diameter of the lens:

$$f - number = \frac{f}{diameter}$$

(Ex. 1016, Walker at 59; Ex. 2001, Milster Decl., ¶ 41.)

The diameter of the lens determines how much total light is collected per unit time by the lens from a given scene. (Ex. 2001, Milster Decl., ¶ 42.) Under certain approximations, doubling the diameter increases the amount of light collected by a factor of four. (*Id.*) The focal length determines the image size on the sensor and thus determines the size of the distribution area of the

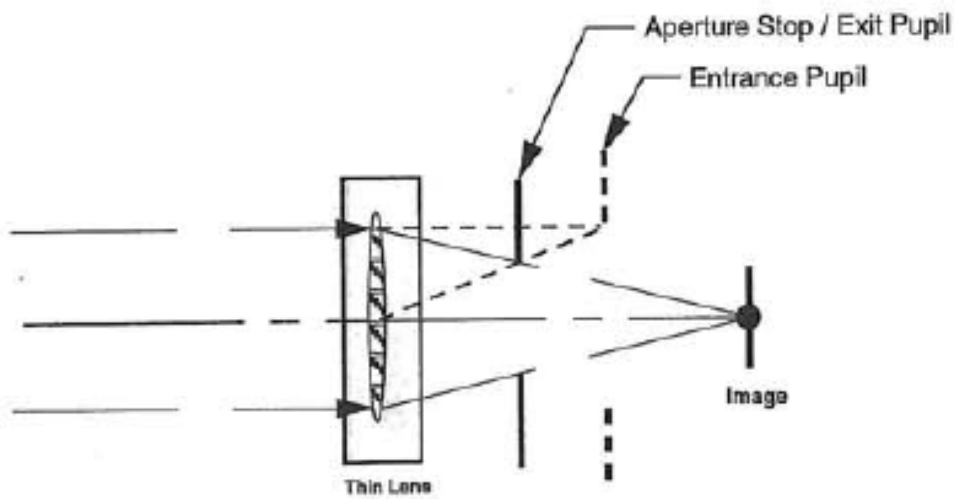
collected light. (*Id.*) Doubling the focal length increases the area illuminated in the image by a factor of four and reduces the intensity of the light in any given part of the image by a factor of four. (*Id.*) So, if both the diameter and focal length are doubled, then the effects approximately cancel out, and the brightness of the image at the sensor is left unchanged, although the image is larger. (*Id.*) In other words, it is the ratio of the focal length and the diameter that most strongly effects the image brightness. (*Id.*)

Because the diameter is in the denominator, a smaller f-number corresponds to a brighter image for a fixed focal length. In more complicated lens systems with multiple lens elements, such as those at issue in this IPR, the amount of light collected no longer depends on the diameter of a single lens (or of a single lens surface), and the effective focal length (EFL) is a function of the lens elements and their spacings. (*Id.*, ¶ 43.) One definition of f-number for such systems instead uses the diameter of the "entrance pupil" (EPD), meaning that the formula is changed to:

$$f\text{-}number = \frac{EFL}{diameter} = \frac{EFL}{EPD}$$

(Ex. 1003, Sasián Decl. at 58–39; Ex. 2001, Milster Decl., ¶ 43.)

The concept of the "entrance pupil" is illustrated in the following drawing from Figure 4-2 of Walker:



(Ex. 1016, Walker, p. 61; Ex. 2001, Milster Decl., ¶ 44.)

As shown here, the entrance pupil reflects the size of the bundle of rays parallel to the optical axis of the lens that can enter the lens, travel through the aperture stop, and reach the image plane. Explained another way, the entrance pupil "is the image of the aperture stop as seen when looking from the object side of the lens." (Ex. 1016, Walker, p. 60; Ex. 2001, Milster Decl., ¶ 45.)

IV. LEGAL STANDARDS

The petitioner has the burden to clearly set forth the basis for its challenges in the petition. *Harmonic Inc. v. Avid Tech., Inc.*, 815 F.3d 1356, 1363 (Fed. Cir.2016) (citing 35 U.S.C. § 312(a)(3) as "requiring IPR petitions to

identify 'with particularity ... the evidence that supports the grounds for the challenge to each claim'"). The burden of persuasion "never shifts to the patentee." *Dynamic Drinkware, LLC v. Nat'l Graphics, Inc.*, 800 F.3d 1375, 1378 (Fed. Cir. 2015).

A petitioner may not rely on the Board to substitute its own reasoning to remedy the deficiencies in a petition. *SAS Inst., Inc. v. Iancu*, 138 S. Ct. 1348, 1355 (2018) ("Congress chose to structure a process in which it's the petitioner, not the Director, who gets to define the contours of the proceeding."); *In re Magnum Oil Tools Int'l, Ltd.*, 829 F.3d 1364, 1381 (Fed. Cir. 2016) (rejecting the Board's reliance on obviousness arguments that "could have been included" in the petition but were not, and holding that the Board may not "raise, address, and decide unpatentability theories never presented by the petitioner and not supported by the record evidence"); *Ariosa Diagnostics v. Verinata Health, Inc.*, 805 F.3d 1359, 1367 (Fed. Cir. 2015) (holding that "a challenge can fail even if different evidence and arguments might have led to success"); *Wasica Finance GMBH v. Continental Auto. Systems*, 853 F.3d 1272, 1286 (Fed. Cir. 2017) (holding that new arguments in a reply brief are "foreclosed by statute, our precedent, and Board guidelines").

The petitioner cannot satisfy its burden of proving obviousness by employing "mere conclusory statements." *Magnum*, 829 F.3d at 1380. As the Federal Circuit has explained, "obviousness concerns whether a skilled artisan not only *could have made* but *would have been motivated to make* the combinations or modifications of prior art to arrive at the claimed invention." *Belden Inc. v. Berk-Tek LLC*, 805 F.3d 1064, 1073 (Fed. Cir. 2015); *Hulu, LLC v. Sound View Innovactions, LLC*, Case No. IPR2018-00582, Paper 34 at 21–22 (Aug. 5, 2019) (informative).

V. LEVEL OF ORDINARY SKILL IN THE ART (POSITA)

In his declaration, Dr. Sasián offers his opinion that a person having ordinary skill in the art ("POSITA"):

> would include someone who had, at the priority date of the '897 Patent, (i) a Bachelor's degree in Physics, Optical Sciences, or equivalent training, as well as (ii) approximately three years of experience in designing multi-lens optical systems. Such a person would have had experience in analyzing, tolerancing, adjusting, and optimizing multi-lens systems for manufacturing, and would have been familiar with the specifications of lens systems and their fabrication. In addition, a POSITA would have known how to use lens design software such as Code V, Oslo, or Zemax, and would have taken a lens design course or had equivalent training.

(Ex. 1003, Sasián Decl., ¶¶ 19–20.) Corephotonics' expert Dr. Milster has applied the same definition of ordinary skill in his analysis. (Ex. 2001, Milster Decl., ¶ 19.)

The '897 patent claims priority by a series of continuations to an application that was filed on January 30, 2017 and issued as U.S. Patent No. 9,857,568. (Ex. 1001, '897 patent at 1:5–10.) The '897 patent also claims priority by a series of continuations and continuations-in-part to a provisional patent application that was filed on July 4, 2013. (Ex. 1001, '897 patent at 1:5–12.)

In his declaration, Dr. Sasián appears to assume that the relevant effective filing date for assessing the level of skill in the art is July 4, 2013. (Ex. 1003, Sasián Decl., ¶¶ 18–21.) The only claims that Dr. Sasián contends have a January 30, 2017 priority date are claims 16 and 30. (Ex. 1003, Sasián Decl., ¶ 33.) Apple and Dr. Sasián do not appear to dispute that the challenged claims other than claims 16 and 30 have an effective filing date of July 4, 2013. For the purposes of evaluating the level of skill in the art, Dr. Milster has considered the level of skill in the art as of January 30, 2017 for claims 16 and 30, and as of July 4, 2013 for the other challenged claims, and this response does the same. (Ex. 2001, Milster Decl., ¶ 23.) However, none of the arguments set

forth herein would change if one assumed a July 4, 2013 date for claims 16 and 30 or a January 30, 2017 for any of the other claims. (*See id.*)

VI. CLAIM CONSTRUCTION

Apple's petition applies two claim constructions for terms that the Board has previously construed in IPRs concerning U.S. Patent No. 9,402,032 and 9,568,712, patents to which the '897 patent claims priority:

> Effective Focal Length (EFL): "the focal length of a lens assembly."
>
> Total Track Length (TTL): "the length of the optical axis spacing between the object-side surface of the first lens element and one of: an electronic sensor, a film sensor, and an image plane corresponding to either the electronic sensor or a film sensor."

(Paper 2 at 7–8; IPR2018-01140, Paper 37 at 10–18.) The Board also adopted these same constructions in IPR2019-00030 concerning the '568 patent, which contains the same specification as the '897 patent. (IPR2019-00030, Paper 32 at 8, 14–15.)

The Board's Institution Decision applied these constructions, but invited the parties to address the proper construction of "Total Track Length," in light of a different construction for this term proposed by Apple in IPR2020-00877. (Paper 7 at 8–9.)

Corephotonics does not believe that any dispute between the parties in this IPR depends on the construction of EFL, TTL, or of any other claim term. Accordingly, Corephotonics submits that the Board should refrain from construing any terms in the patent for the purposes of this proceeding.

VII. PRIOR ART REFERENCES

A. Ogino

Ogino issued on September 8, 2015 as U.S. Patent No. 9, 128,267. (Ex. 2015.) Apple contends that Ogino has an effective filing date of March 29, 2013, based upon the filing date of the corresponding Japanese patent application. (Petition at 9.)

As described in Ogino's abstract, its invention is a system of five lenses with a particular set of shapes:

> An imaging lens substantially consists of, in order from an object side, five lenses of a first lens that has a positive refractive power and has a meniscus shape which is convex toward the object side, a second lens that has a biconcave shape, a third lens that has a meniscus shape which is convex toward the object side, a fourth lens that has a meniscus shape which is convex toward the image side; and a fifth lens that has a negative refractive power and has at least one inflection point on an image side surface. Further, the following conditional expression (1) is satisfied.
>
> $1.4<f/f1<4$ (1)

(Ex. 1005, Ogino, Abstract.)

This same set of shapes and conditions is described as the "imaging lens of the present invention" in Ogino's "Summary of the Invention" section. (Ex. 1005, Ogino at 2:1–16; Ex. 2001, Milster Decl., ¶ 51.)

Ogino describes six examples of this basic system, each of which has this same pattern of shapes:

> As in the first embodiment, the imaging lenses according to the second to sixth embodiments of the present invention substantially consist of, in order from the object side, five lenses of: the first lens L1 that has a positive refractive power and has a meniscus shape which is convex toward the object side; the second lens L2 that has a biconcave shape; the third lens L3 that has a meniscus shape which is convex toward the object side; the fourth lens L4 that has a meniscus shape which is convex toward the image side; and the fifth lens L5 that has a negative refractive power and has at least one inflection point on an image side surface.

(Ex. 1005, Ogino at 13:5–16.)

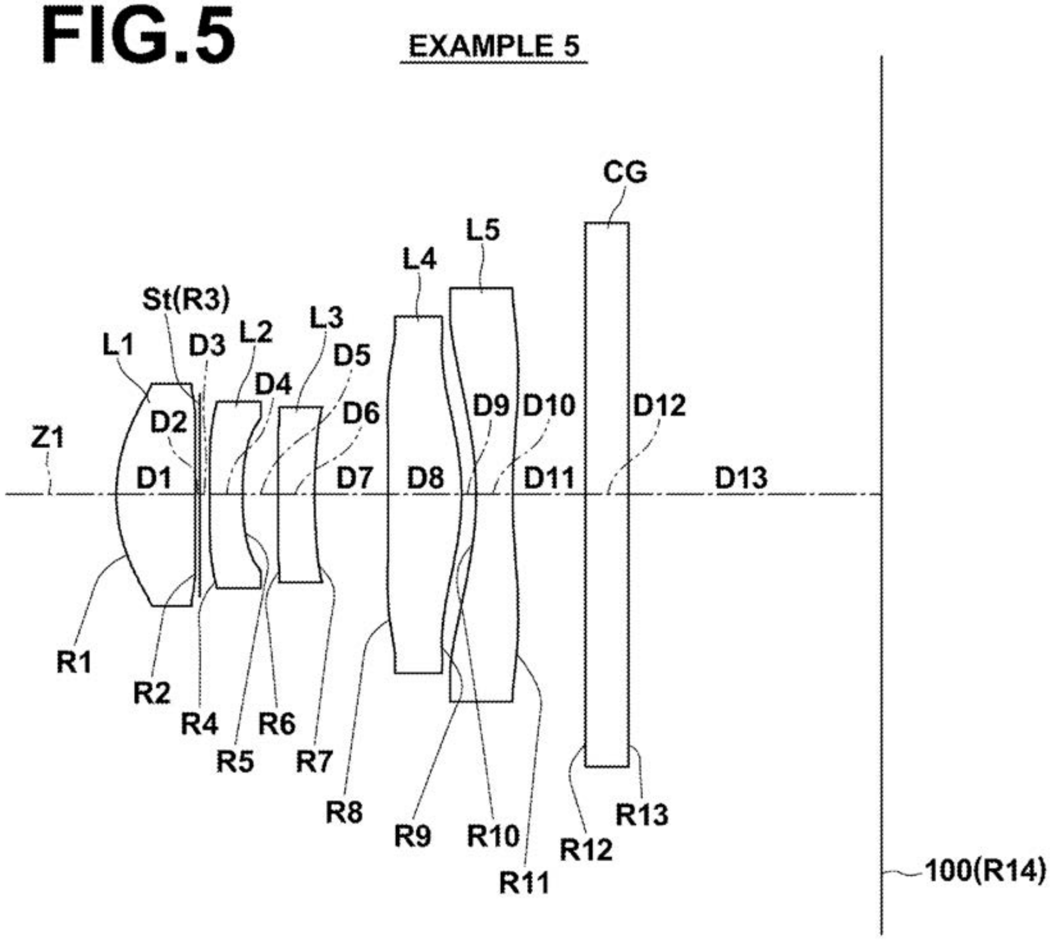
Ogino explains the reasons for using each of these shapes, for example in lines 7:28–8:42. For example:

> As shown in the embodiments, by making the first lens L1, which is a lens closest to the object, have a positive refractive power and have a meniscus shape which is convex toward the object side in the vicinity of the optical axis, the position of the rear side principal point of the first lens L1 can be set to be close to the object, and thus it is possible to appropriately reduce the total length.

(Ex. 1005, Ogino at 7:31–37; Ex. 2001, Milster Decl., ¶ 53.)

Apple's grounds utilizing Ogino are all based on Ogino's "Example 5" or modifications to that example. (Ex. 1003, Sasián Decl., ¶¶ 46, 51, 61.) The lens elements of Example 5 are shown in Ogino, Figure 5:

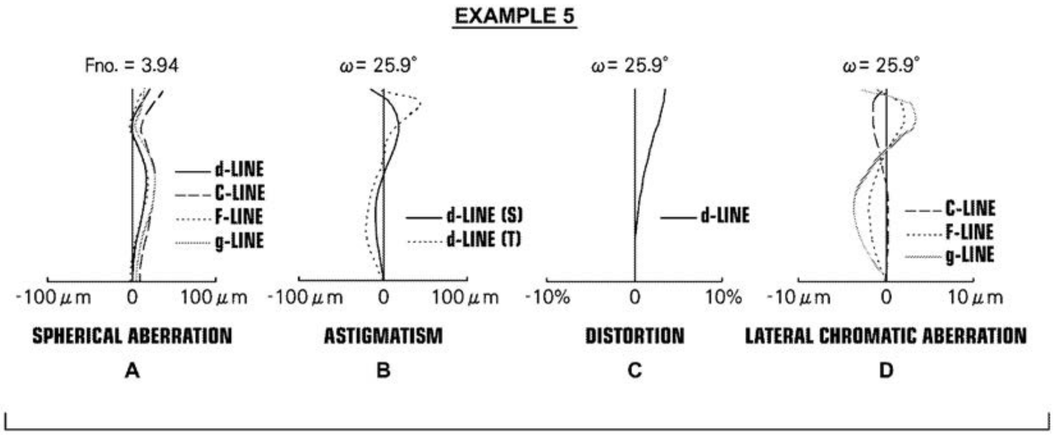
FIG.5



(Ex. 1005, Ogino, Figure 5; Ex. 2001, Milster Decl., ¶ 54.)

Figure 12 of Ogino provides certain optical characteristics of Example 5, including its f-number of 3.94 and half-angle of view ω=25.9°:

FIG.12



(Ex. 1005, Ogino, Figure 12; Ex. 2001, Milster Decl., ¶ 55.)

The lens prescription for Example 5 is given in Ogino Tables 9 and 10:

TABLE 9

EXAMPLE 5
f = 5.956, Bf = 2.438, TL = 5.171

Si	Ri	Di	ndj	νdj
*1	1.12444	0.546	1.54488	54.87
*2	252.97534	0.030		
3 (APERTURE STOP)	∞	0.069		
*4	−18.78836	0.227	1.63351	23.63
*5	2.25616	0.243		
*6	506.45581	0.253	1.63351	23.63
*7	4.36560	0.506		
*8	−99.83715	0.506	1.63351	23.63
*9	−1.70702	0.100		
*10	−2.17464	0.253	1.54488	54.87
*11	3.61429	0.500		
12	∞	0.300	1.51633	64.14
13	∞	1.740		
14	∞			

*ASPHERIC SURFACE

TABLE 10

EXAMPLE 5 - ASPHERIC SURFACE DATA

SURFACE NUMBER	KA	A4	A6	A8
1	6.9377302E−01	−8.6315370E−03	−2.9322827E−03	−2.8236519E−01
2	1.0000090E+00	1.0299728E−02	−3.3338883E−02	−3.5854402E−01
3	9.8073731E+00	4.1860316E−01	2.4161475E−01	−7.6083670E−01
4	3.1182039E+00	4.6995645E−01	1.5149631E+00	−2.7101440E+00
5	6.1881621E−01	−1.9777356E−01	1.5104859E+00	−1.5044509E+00
6	9.9999979E−01	−1.3815608E−01	8.2457564E−01	−4.9516542E−01
7	3.2258104E−01	−7.2840681E−02	1.5663313E−01	9.8367802E−02
8	−2.6292010E+00	1.1379689E−01	−1.7291781E−02	2.9845655E−02
9	−1.4000002E+01	−4.4092972E−02	9.9278653E−02	−7.7922450E−02
10	1.3000586E−01	−1.8315230E−01	1.3758774E−01	−9.0542240E−02
	A10	**A12**	**A14**	**A16**
1	3.6582042E−01	−4.2487703E−01	−2.2631039E−01	−2.0344291E−02
2	−2.1599412E−01	−4.4977846E−01	2.5600140E+00	−1.9687116E+00
3	−7.7068397E−01	2.7743135E−01	2.0383002E+00	7.4259109E−01
4	1.3698992E+01	−3.8132984E+01	5.1107685E+01	−2.7851932E+01
5	1.4799995E+00	1.8815842E+01	−1.1654772E+02	1.7961509E+02
6	2.3119410E+00	−1.5309306E+01	2.6135941E+01	−1.0762516E+01
7	−2.7569022E−01	1.7783105E−01	−4.9261478E−02	3.9419268E−03
8	1.7970251E−04	−2.1611961E−02	4.0098433E−03	1.4790761E−03
9	2.0967820E−02	4.6775947E−03	−9.1757326E−04	−4.2752923E−04
10	4.2054637E−02	−1.3115957E−02	2.7031329E−03	−1.9876871E−04

(Ex. 1005, Ogino, column 21; Ex. 2001, Milster Decl., ¶ 56.)

B. Bareau

Bareau is an article by Jane Bareau and Peter P. Clark, titled "The Optics of Miniature Digital Camera Modules." (Ex. 1012.) Dr. Sasián states that this was presented at an International Optical Design Conference in June 2006 and that it was published in SPIE Proceedings Vol. 6342 "a few months after the conference." (Ex. 1003, Sasián Decl., ¶ 47.)

Apple does not rely on any detailed lens design from Bareau or any teachings of how a lens designer would create a detailed lens design. (Ex. 2001, Milster Decl., ¶ 58.) Rather, Apple and Dr. Sasián rely on Bareau listing an f-

number of 2.8 in its "typical lens specifications for a ¼″ sensor format." (Ex. 1003, Sasián Decl., ¶¶ 51–53; Ex. 1012, Bareau at 3–4; Ex. 2001, Milster Decl., ¶ 58.)

Other parts of Bareau illustrate an important point relevant to this IPR: the fact that you can simulate a lens design in lens design software such as Zemax does not mean that you can build that design. (Ex. 2001, Milster Decl., ¶ 59.) As Bareau explains:

> Layout drawings can be very misleading. Many times we find ourselves surprised when the mechanical layout of a lens barrel that looked reasonable on paper turns out to be very difficult or impossible to fabricate. Tabs on a barrel that appear substantial in a drawing, are found to be too flimsy to function on the actual part, sharp edges on molded stops don't fill completely because the features are too small.

(Ex. 1012, Bareau at 1; Ex. 2001, Milster Decl., ¶ 59.)

Bareau explains aspects of the shape and size of lens elements, be they made out of plastic or glass, that are particularly problematic when producing miniature lenses like those at issue in this IPR:

> Scaling down such a lens will result in a system that is unmanufacturable. If the design includes molded plastic optics, a scaled down system will result in element edge thicknesses shrinking to the point where the flow of plastic is affected. For glass elements, the edge thicknesses will become too thin to be fabricated without chipping.

(Ex. 1012, Bareau at 1; Ex. 2001, Milster Decl., ¶ 60.)

Bareau explains that the issue of "geometric tolerances," including both in the size and shape of individual lens elements and their alignment within the overall system, "proves to be the greatest challenge of producing these lenses." (Ex. 1012, Bareau at 3; Ex. 2001, Milster Decl., ¶ 61.)

Bareau further explains that there are limits to achievable shapes in miniature lenses. For molded lenses, these limits arise from the properties of the lens material, both in liquid form and in solid form, and from the techniques used to make the mold inserts that the lens parts are formed in. According to Bareau:

> Plastic injection molded optics have minimum edge thicknesses, minimum center thicknesses and range of acceptability for their center to edge thickness ratio that must be met in order that they can be molded. Additionally, the maximum slope that can be diamond-turned in mold inserts and measured in either the lens or the mold is around 45 degrees.

(Ex. 1012, Bareau at 8; Ex. 2001, Milster Decl., ¶ 62.)

As Bareau explains, similar limitations apply to glass lens elements: "Traditional glass lenses have similar types of requirements but with different values." (Ex. 1012, Bareau at 8; Ex. 2001, Milster Decl., ¶ 63.) In molded glass lenses, "surfaces with inflections can only be used under very limited circumstances and flanges can only be formed in a restricted range of shapes,

no sharp corners or abrupt changes in slope are allowed." (Ex. 1012, Bareau at 8; Ex. 2001, Milster Decl., ¶ 63.)

C. Kingslake

Kingslake is a text by Rudolf Kingslake titled "Optics in Photography." (Ex. 1013.) The copyright page contains a copyright date of 1992. (Ex. 1013 at 2.) Apple cites to only a single page from this textbook, page 104. (Ex. 1013 at 3.)

This page contains the beginning of Kingslake's chapter 6, titled "The Brightness of Images." (Ex. 1013.) The only portions of Kingslake that Apple or Dr. Sasián actually quotes are from the first paragraph of this chapter:

> The relation between the aperture of a lens and brightness of the image produced by it on the photographic emulsion is often misunderstood, yet it is of the greatest importance to the photographer who wishes to make the best use of the equipment. The ***tremendous efforts of lens designers and manufacturers*** that have been devoted to the production of lenses of extremely high relative aperture are an indication of the need that exists for brighter images and "faster" lenses.

(Ex. 1013, p. 104 (emphasis added).)

This paragraph refers to "brighter" and "faster" lenses, which as explained above correspond to lenses with smaller f-numbers. (Ex. 2001, Milster Decl., ¶ 67.) Brighter or faster lenses have advantages, in that they are able to capture an image of a given scene with a shorter exposure (which may be

desirable for fast-moving scenes) or to capture a lower-light scene with the same exposure duration. (*Id.*)

However, simply because a property is desirable, does not make it easy to achieve. (*Id.*, ¶ 68.) As Kingslake says, creating lenses with small f-number has required “tremendous efforts of lens designers and manufacturers.” (Ex. 1013, Kingslake, p. 104) It requires more than simply deciding to have larger diameters of lenses and apertures. (Ex. 2001, Milster Decl., ¶ 68.)

D. Chen

The Chen patent issued as U.S. Patent No. 10,324,273 on June 18, 2019 and claims priority to a Chinese patent application filed August 29, 2016. (Ex. 1020, Chen.) It describes “an optical imaging lens set of five lens elements for use in mobile phones, in cameras, in tablet personal computers, or in personal digital assistants.” (Ex. 1020, Chen at 1:17–19.)

Apple’s and Dr. Sasián’s obviousness arguments based on Chen are based on a modification of Chen’s Example 1, which is shown in Chen Figure 6:

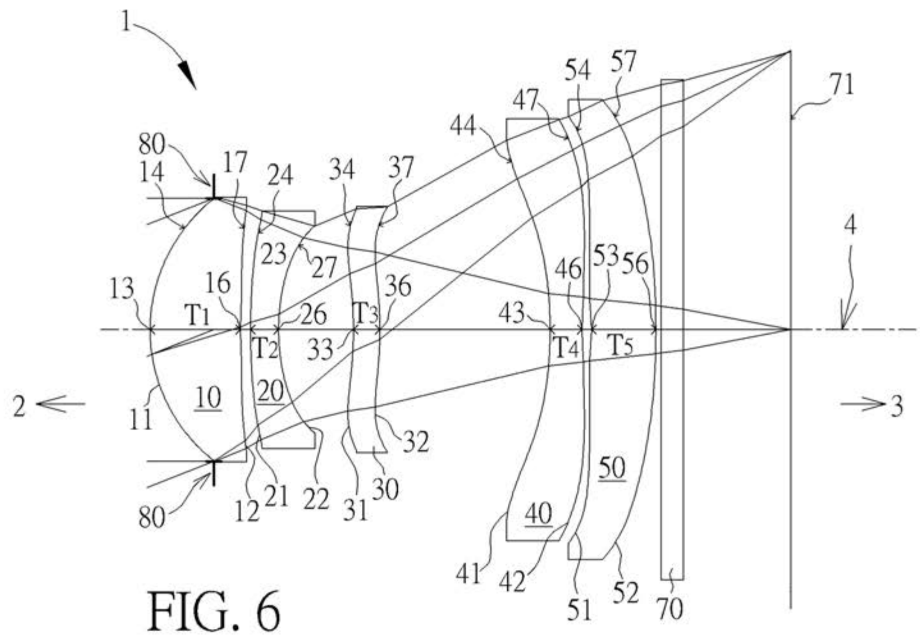


FIG. 6

(Ex. 1020, Chen, Figures 6 and 24, 2:62–63, 8:42–10:12; Ex. 2001, Milster Decl., ¶ 70.)

According to Chen, this lens system has an effective focal length of 6.582 mm (Ex. 1020, Chen, Figure 42) and a TTL of 6.0187 mm (Ex. 1020, Chen at 10:9.) According to Chen, "[g]enerally speaking," each of the five lens elements in this system may be made of "transparent plastic material." (Ex. 1020, Chen at 7:11–22.)

Chen also illustrates an important point concerning lens ray trace diagrams produced using lens design software, such as Chen's figure 6. (Ex. 2001, Milster Decl., ¶ 72.) The lens design software is concerned with the

optically clear aperture of the lens element that light passes through and that bend that light to form an image. (*Id.*) The ray trace diagrams generated by software such as Zemax show those parts of the lens elements. (*Id.*) But a physical lens element (as opposed to one simulated in software) extends beyond the shape drawn by the lens design software at the maximum diameter of where the light passes through the lens. (*Id.*) This is illustrated by Chen Figure 1, which shows "extension parts" E that are part of the lens outside of the light bending portion:

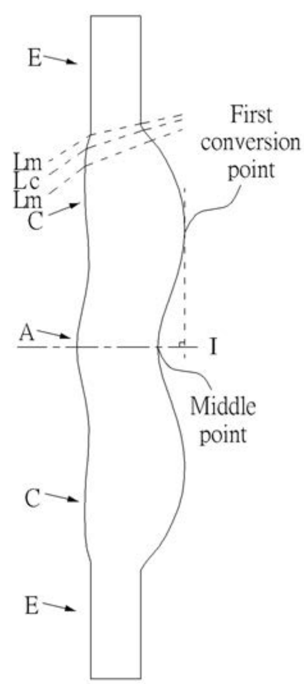


FIG. 1

(Ex. 1020, Figure 1; Ex. 2001, Milster Decl., ¶ 72.)

The extension parts in this lens element appear to serve as flanges for mounting the lens element, like those described in Bareau. (Ex. 1012, Bareau at 8; Ex. 2001, Milster Decl., ¶ 73.)

E. Iwasaki

The Iwasaki patent issued as U.S. Patent No. 9,678,310 on June 13, 2017, and it claims priority to a Japanese patent application filed March 25, 2013. (Ex. 1009.) It describes an "imaging lens . . . constituted essentially by four or more lenses." (Ex. 1009, Iwasaki, Abstract.)

The only aspect of Iwasaki that Apple and Dr. Sasián rely on is the 0.145 mm cover glass used in Iwasaki's examples 1 and 2. (Ex. 1003, Sasián Decl., ¶¶ 72–74; Ex. 1009, Iwasaki, Tables 1 and 3; Ex. 2001, Milster Decl., ¶ 75.)

F. Beich

Beich is a paper titled "Polymer Optics: A manufacturer's perspective on the factors that contribute to successful programs," which lists William S. Beich and Nicholas Turner as its authors. (Ex. 1007, Beich at 1.) According to a statement on its first page, it was published in the Proceedings of SPIE in 2010. (Ex. 1007, Beich at 1.)

Beich discusses various considerations and rules of thumb that relate to the manufacturability of lenses using injection molding methods. According to Dr. Sasián "a POSITA looking to implement optical element specifications using injection molding methods would look to Beich for guidance on limitations and parameters that affect lens manufacturability." (Ex. 1003, Sasián Decl., ¶ 78; Ex. 2001, Milster Decl., ¶ 77.)

Beich explains that the "unique nature of injection molding demands a very disciplined approach during the component design and development phase." (Ex. 1007, Beich at 2.) The paper describes aspects of the injection molding process, such as the "runner system" of channels that convey molten plastic into the mold insert through the sides of the lens. (Ex. 1007, Beich at 6.) Beich explains that "[o]ptics with extremely thick centers and thin edges are very challenging to mold," and it provides a set of "rules of thumb," including that the center thickness to edge thickness ratio for a lens element should be less than "3:1" and that the lens diameter tolerance is ±0.020 mm. (Ex. 1007, Beich at 7; Ex. 2001, Milster Decl., ¶ 78.)

VIII. ARGUMENT

A. Ground 2 – Claims 2, 5, 6, 18, and 21–23 Are Not Obvious over Ogino in view of Bareau

According to Dr. Sasián, Ogino Example 5 satisfies each of the elements of claims 1 and 17 of the ’897 patent. Dependent claims 2, 5, 6, 18, and 21–23 each add the requirement that f-number be less than 2.9, or in the case of claim 23 that the f-number equal 2.8. But, Ogino Example 5 has an f-number of 3.94. Ogino Figure 12. (Ex. 2001, Milster Decl., ¶ 79.)

Dr. Sasián shows how Ogino Example 5 ***could*** be modified using the Zemax software, to reduce the f-number while leaving all the other characteristics of Example 5 that Apple relies on to satisfy claims 1 and 17 unchanged. However, the fact that Dr. Sasián, a highly skilled and well-regarded lens designer with decades of experience who literally “wrote the book” on the subject could modify Ogino Example 5 in this way in 2020, with the claims of the ’897 patent in front of him, does not demonstrate that a lens designer of merely ordinary skill ***would*** have thought to follow this approach in 2013. (Ex. 2001, Milster Decl., ¶ 80)

Bareau suggests that a lens with f-number of 2.8 was desirable for use in a miniature digital camera in 2013. But Bareau also shows that lenses with f-number 2.8 were already commercially available years earlier, in 2006. Ogino

itself describes other lenses with f-numbers of 2.45, 2.46, 2.47, 2.64, 3.04. (Ex. 1005, Figures 8–11, 13.) If a POSITA looking at Ogino felt that an f-number of 3.94 was not suitable for their particular application and wanted an f-number of 2.8 instead, that person would naturally look to one of Ogino's other designs, with f-number closer to 2.8, or to one of the hundreds of other miniature lens designs available in the patent literature or in the market. (Ex. 2001, Milster Decl., ¶ 81.) Dr. Sasián provides no explanation for why a POSITA would pick Ogino Example 5, the Ogino lens that is farthest from this desired f-number and modify it dramatically as Dr. Sasián proposes. (*Id.*)

Further, the result of Dr. Sasián's modification to Ogino Example 5 does not satisfy all of the "typical lens specifications" from Bareau. (*Id.*, ¶ 82) Bareau's table of specifications lists a field of view "FOV" of 60 degrees, but Bareau suggests that larger angles such as 66 degrees are also "typical." (Ex. 1012, Bareau at 3.) The unmodified Ogino Example 5 has a half-angle field of view ω=25.9°, or a full field of view of approximately 52°. (Ex. 2001, Milster Decl., ¶ 82.) Dr. Sasian's modifications reduced the field of view to "+/-20°," i.e., to a full field of view of 40°. (Ex. 1003, Sasián Decl. at 104 and figures on 105 and 106; Ex. 2001, Milster Decl., ¶ 82.) Dr. Sasián does not explain why a POSITA seeking to modify Ogino Example 5 based upon the

specification in Bareau would do so in a way that allowed it to satisfy one of Bareau's specifications but that moved it further away from Bareau's other specifications. (*Id.*)

Dr. Sasián does point to a patent by Parulski (Ex. 1014) as an example of a cell phone with both wide and narrow angle lenses, but Parulski does not specify any f-number for its narrow angle lenses. (Ex. 2001, Milster Decl., ¶ 83.) Nothing cited by Dr. Sasián suggests that an f-number of 2.8 was desirable in the context of a narrower-angle lens, and nothing suggests that a POSITA would have been motivated to modify Ogino example 5 to reduce both the f-number and the field of view. (*Id.*)

Even if there were some evidence that a POSITA would have considered the result of the modifications that Dr. Sasián performs to Ogino Example 5 to be desirable, he does not show that a POSITA would have actually followed the approach that he describes. (Ex. 2001, Milster Decl., ¶ 84.) In modifying Ogino Example 5, Dr. Sasián kept the number of lens elements, the powers of the lens elements, their thicknesses, and their spacings unchanged, except for a small change to the thickness of the first lens element. (Ex. 1003, Sasián Decl. at 104; Ex. 2001, Milster Decl., ¶ 84.) He made the small change in thickness of the first lens element, from 0.546 mm (Ex. 1005, Ogino Table 9)

to 0.600 mm (Ex. 1003, Sasián Decl. at 107) by hand. (Ex. 2003, Sasián Depo. at 24:14–25:10.) By keeping these parameters (nearly) unchanged, Dr. Sasián ensured that the values of EFL, TTL, lens powers, and lens gaps needed to satisfy other claim elements remained unchanged. (Ex. 2001, Milster Decl., ¶ 84.)

In other words, in modifying Ogino Example 5, Dr. Sasián changed the one parameter by hand that needed to be changed to satisfy the claims, the f-number, while forcing the other parameters to stay (nearly) the same, so that the other parameters of the claims did not change. (Ex. 2001, Milster Decl., ¶ 85.)

This approach is a natural approach if the goal is to modify Ogino to satisfy the '897 patent claims, but it is not the approach that a POSITA would actually follow. (Ex. 2001, Milster Decl., ¶ 86.) A lens design such as Ogino Example 5 is defined by more than 100 numerical parameters, shown in tables 9 and 10 of Ogino. (*Id.*) There are a vast number of ways that various combinations of these parameters could be varied. (*Id.*) Further, entire lens elements can be added or removed, substantially increasing the space of available designs. (*Id.*) The section of Dr. Sasián's lens design textbook that discusses

using lens design software describes 20 "well-known techniques for modifying and improving a lens" for purposes such as to decrease the f-number. (Ex. 2004, Sasián at 133–134; Ex. 2001, Milster Decl., ¶ 86.) Following these "well-known" techniques might very well have led a POSITA to change Ogino Example 5 in a direction very different from what Dr. Sasián proposes, in a way that did not satisfy any of the claims of the '897 patent. (Ex. 2001, Milster Decl., ¶ 86.)

But more fundamentally, a POSITA looking at Ogino and seeking to meet the specifications of Bareau would have seen that there were already lens designs in Ogino that nearly did so, such as Example 6, with its f-number of 2.64 and field of view of 2×29.8° = 59.6°. (Ex. 1005, Ogino, Figure 13; Ex. 2001, Milster Decl., ¶ 87.) They would not have been motivated to instead look to modifying Example 5, just to obtain a lens that was ***further*** from Bareau's specifications than Example 6. (*Id.*)

In addition, a POSITA would have recognized that the lens design that Dr. Sasián created was not manufacturable. (Ex. 2001, Milster Decl., ¶ 88.) That is, the lens has a shape that lens design software such as Zemax will happily perform ray trace calculations on, but that is extremely difficult to construct in a useful physical lens. (*Id.*)

Dr. Sasián has previously offered the opinion that a POSITA would know that the lenses described in Ogino would most likely be made of injection-molded plastic. Specifically, Dr. Sasián noted that:

> While Ogino does not specifically indicate that its lens elements can be plastic, a POSITA would recognize that the index of refraction and Abbe number of the lens elements specified in Example 6 of Ogino are within the range of values of plastic materials used for cell phone lenses.
>
> Further lens elements of the sizes and asphericities described in Ogino would preferably be made of plastic via injection molding processes. See Ex.1019, p.34.14 (pdf p.80). A POSITA would also recognize that when designing lens elements for crafting via injection molding, a number of manufacturing realities apply that all promote maximizing the thickness of the lens element at the edge.

(Ex. 2009, IPR2019-00030 Sasián Decl. at 69; Ex. 2001, Milster Decl., ¶ 89.)

While this earlier statement of Dr. Sasián relates to Ogino Example 6, it applies similarly to Ogino Example 5. (Ex. 2001, Milster Decl., ¶ 90.) For example, the indices of refraction and Abbe numbers for the materials used in Example 5 are the same as those in Example 6 (Ex. 1005, Ogino, Tables 9, 11), indicating that the same plastic materials were used in both examples. (Ex. 2001, Milster Decl., ¶ 90.)

A POSITA would understand that a lens intended for use in a compact camera for a mobile device like Ogino (Ex. 1005, Ogino at 1:7–15) would be

made using injection molded plastic. (Ex. 2001, Milster Decl., ¶ 91.) For example, Bareau states that in miniature digital camera modules: "The ***majority of these lenses are all-plastic*** although some incorporate one glass element (usually the front element) for the advantages of high-index refraction and color correction." (Ex. 1012, Bareau at 8.) (Ogino Example 5 does not follow the minority approach of a different non-plastic material for the first lens, as the first and fifth lens both use the same material, Ex. 1005, Ogino, Table 9 (Ex. 2001, Milster Decl., ¶ 91).) Likewise, Clark (one of the authors of the Bareau article) writing about mobile device camera lenses in 2014 wrote: "Conventional lens designs are multi-element injection molded plastic lenses assembled in a plastic barrel, as they were in 2006." (Ex. 2005, Clark at 3; Ex. 2001, Milster Decl., ¶ 91.)

To the extent that glass were used in a lens design such as Ogino's, it would also be molded, as molding is the practical approach to making aspheric lenses, such as those in Ogino:

> One of the primary advantages of molded optics has always been the use of aspheric surfaces. Aspheric surfaces are simply surfaces that are not spherical. Historically, ***most optical surfaces have been spherical (or flat) due to ease of fabrication and testing with the exception of molded optics***. Aspheric surfaces have long been the standard in molded optics, regardless of process, again due to ease of manufacture. The mold manufacturing process is well suited to aspheric manufacturing, and

> only having to cut a small number of molds to make a large quantity of optics made an increase in tooling cost trivial when amortized over a molding run.

(Ex. 2006, Symmons at 6; Ex. 2001, Milster Decl., ¶ 92.)

Dr. Milster has written a chapter in the Handbook of Optics which contains a section on molded glass and plastic optics. (Ex. 2008, Handbook of Optics, Section 7.5.) As he explains there:

> Molded lenses become especially attractive when one is designing an application that requires aspheric surfaces. Conventional techniques for polishing and grinding lenses tend to be time-expensive and do not yield good piece-to-piece uniformity. Direct molding, on the other hand, eliminates the need for any grinding or polishing.

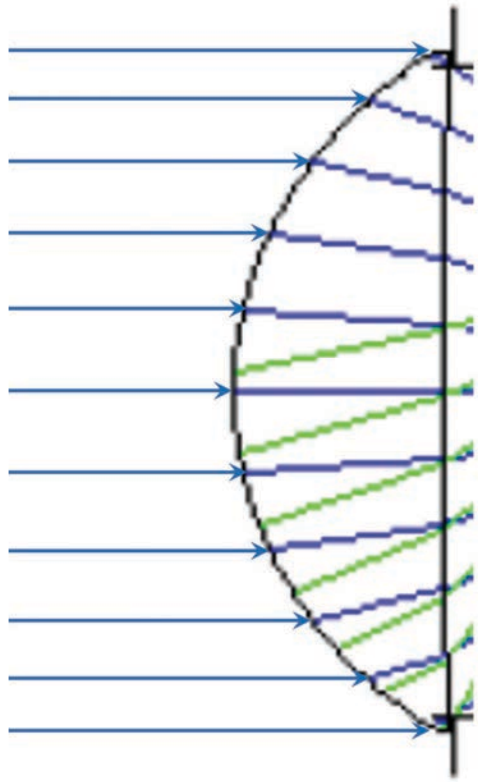
(Ex. 2008, Handbook of Optics, at 7.5–7.6; Ex. 2001, Milster Decl., ¶ 93.)

The modified lenses discussed by Dr. Sasián have the same indices of refraction and Abbe number as in Ogino's example 5, indicating that these modified lenses would use the same (likely plastic) materials as Ogino. (Ex. 1003, Sasián Decl. at 107, 111; Ex. 1005, Ogino, Table 9; Ex. 2001, Milster Decl., ¶ 94.)

The main manufacturability problems with Dr. Sasián's f-number 2.8 modification of Ogino concerns the edges of the first lens element:

(Ex. 1003, Sasián Decl. at 107; Ex. 2001, Milster Decl., ¶ 95.)

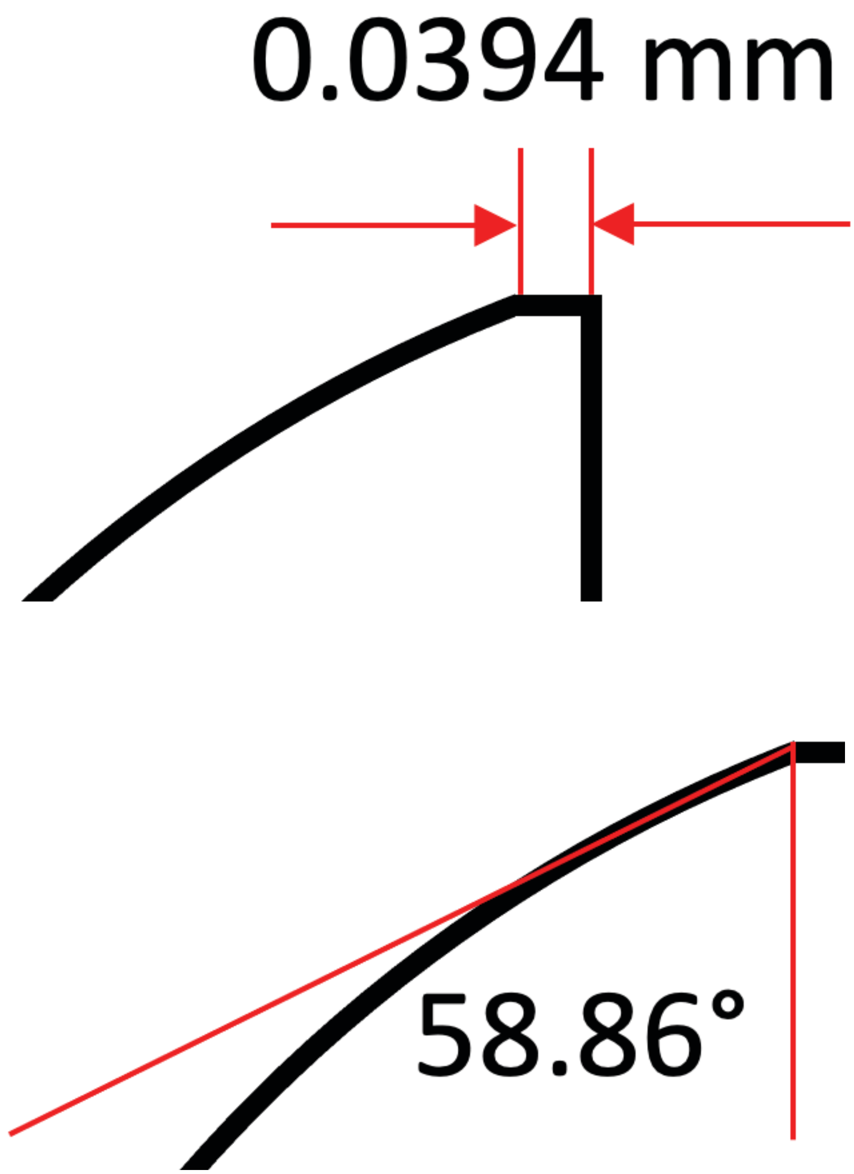
The left surface of this of this excerpt is the object side surface of the first lens. (Ex. 2001, Milster Decl., ¶ 96.) The blue rays of this drawing are the rays of the bundle that defines the entrance pupil. (*Id.*) As the following drawing illustrates, the light forming these blue rays enters as a bundle of parallel rays from the left before being bent by the lens front surface:



(Ex. 2001, Milster Decl., ¶ 96.)

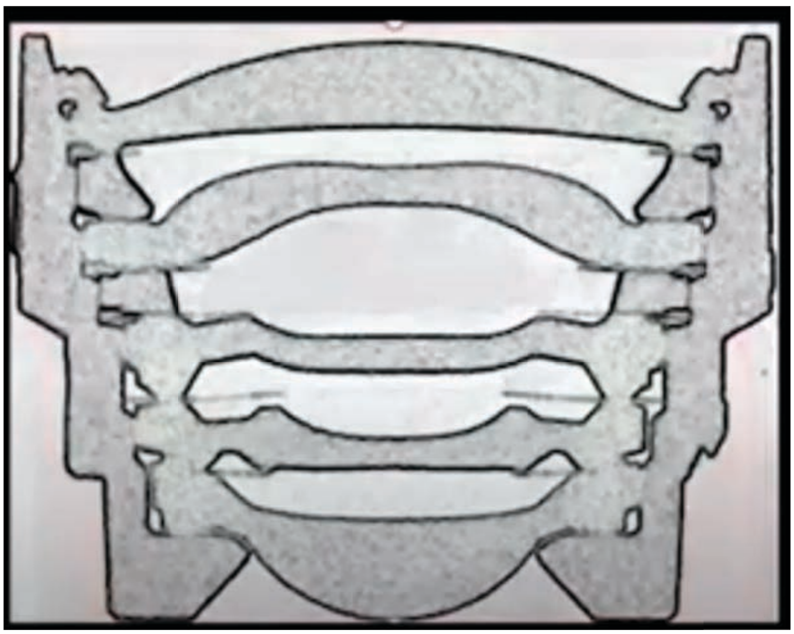
The entrance pupil diameter (part of the formula for f-number) is the diameter of this bundle of rays, which in turn is nearly the full diameter of the object-side lens surface in this drawing. (Ex. 2001, Milster Decl., ¶ 97.) In other words, this lens element needs to be at least the diameter shown here in order to achieve the f-number = 2.8 that Dr. Sasián sought to obtain. (*Id.*) Put another way, the clear aperture of the first surface needs to be at least as large as shown in this drawing to achieve the f-number Dr. Sasián sought. (*Id.*)

The resulting shape has a very narrow edge and a large slope at that edge. According to Dr. Milster's calculations, the edge thickness is only 0.0394 mm (or 39.4 microns), and the slope is 58.86°:



(Ex. 2001, Milster Decl., ¶ 98, Appx. § XI.A.)

This edge thickness of 39.4 µm (microns) is roughly half the width of a typical human hair, commonly taken to be 75 µm.[1] (Ex. 2001, Milster Decl., ¶ 99.) This is not the edge of a realistic, practical lens. (*Id.*) To see why, it is useful to see an actual commercial lens, as in the following X-ray CT image that Dr. Milster had taken as part of his work prior to this IPR[2]:

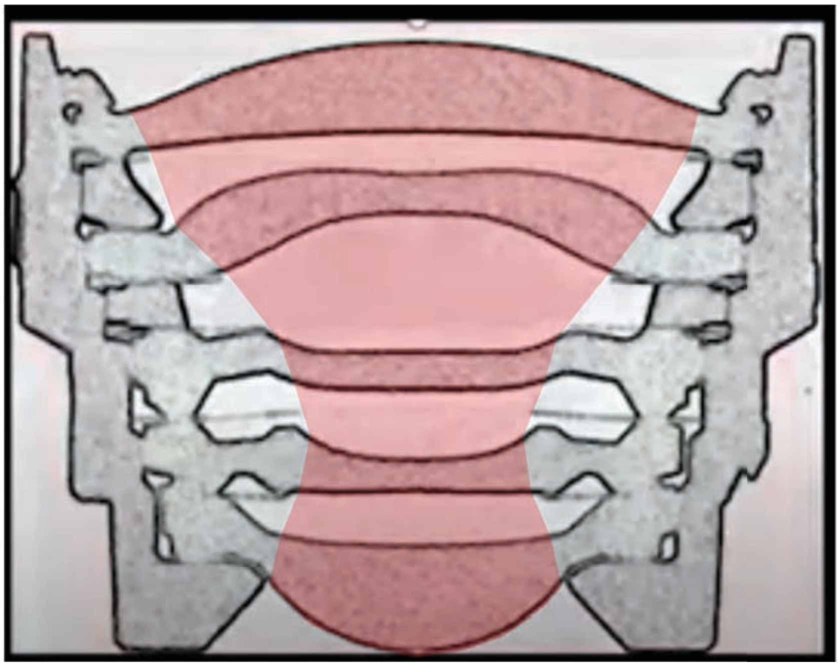


(Ex. 2001, Milster Decl., ¶ 99.)

This lens has five plastic elements (gray), with air gaps (white) between them. (Ex. 2001, Milster Decl., ¶ 100.) The bottom of this picture is the object

[1] https://en.wikipedia.org/wiki/Hair%27s_breadth
[2] A YouTube video of this work is available at https://www.youtube.com/watch?v=E8nE8aBSiJQ.

side, and the top is the image side. (*Id.*) The portion of the lens that light actually passes through is (very) roughly shown in the red shading below:



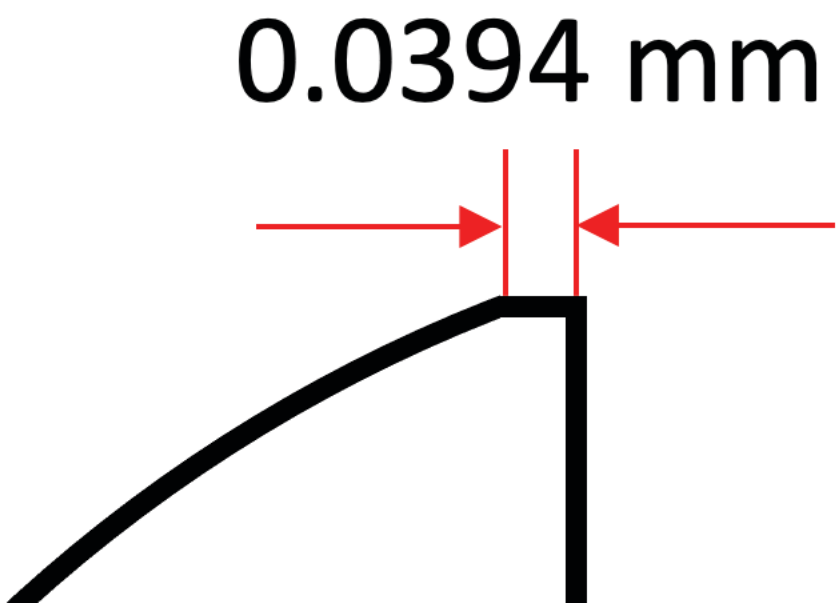
(Ex. 2001, Milster Decl., ¶ 100.)

The thin black structures protruding from left and right are baffles. (*Id.*, ¶ 101.) There are two important things to note concerning the lens elements in this design. (*Id.*) First, each element has a thick mounting flange at its edge, to mount it physically to the roughly cone-shaped lens barrel. (*Id.*) Second, the smoothly curved surfaces in the center of each lens element extend beyond the "clear aperture" where light actually passes through the lens. (*Id.*) Parts of the curved surfaces are in the shadow of the baffles. (*Id.*) In other words, the

curved portions of the lens elements are "oversized" relative to their clear apertures. (*Id.*)

Zemax's ray traces are only concerned with the parts of the lens elements that bend light, i.e., with their clear apertures. (*Id.*, ¶ 102.) The oversized portions and the mounting portions of the lenses are not included in the Zemax designs from Dr. Sasián. (*Id.*) But a POSITA would understand they need to be there in the actual lens. (*Id.*)

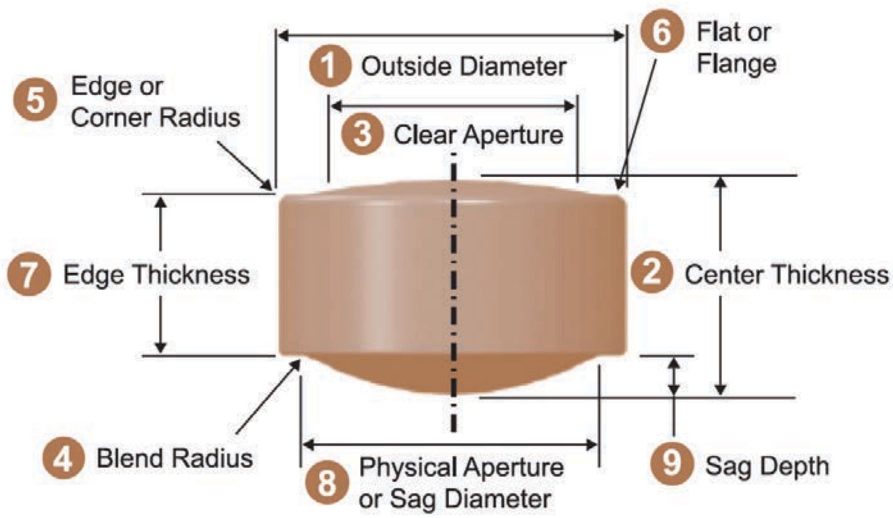
Oversizing is necessary because a lens cannot be made with perfectly sharp corners and edges. (*Id.*, ¶ 103.) In molded lenses, one reason for this is surface tension of the lens material. (*Id.*) If one attempted to inject plastic or glass into a mold with sharp corners such as shown in the Zemax drawing, the liquid would not fill the corners, but would rather form a rounded surface, which would bend light differently than the ideal shape in Zemax:



(Ex. 2001, Milster Decl., ¶ 103.)

In addition, there are limits to the ability to make molds with such sharp corners in the first place, as the diamond-tipped tools typically used to make them have a finite width and are not infinitely sharp. (*Id.*, ¶ 104)

As explained in the Field Guide to Molded Optics, actual molded lenses have rounded corners:



❺ **Edge radius** or **corner radius** (R_c)

The radius on the outside diameter due to volumetric molding.

(Ex. 2006, Symmons, pp. 87–88; Ex. 2001, Milster Decl., ¶ 105.)

Even if the surface tension and other limitations of injection molding were not a factor, practical lenses will have rounded or chamfered corners rather than sharp 90° corners, regardless of the technology used to make them. (Ex. 2001, Milster Decl., ¶ 106.) As Dr. Sasián notes in his textbook, "[i]t is imperative that a bevel, or protective chamfer, is specified to avoid the lens edge easily chipping." (Ex. 2004, Sasián at 112; Ex. 2001, Milster Decl., ¶ 106.)

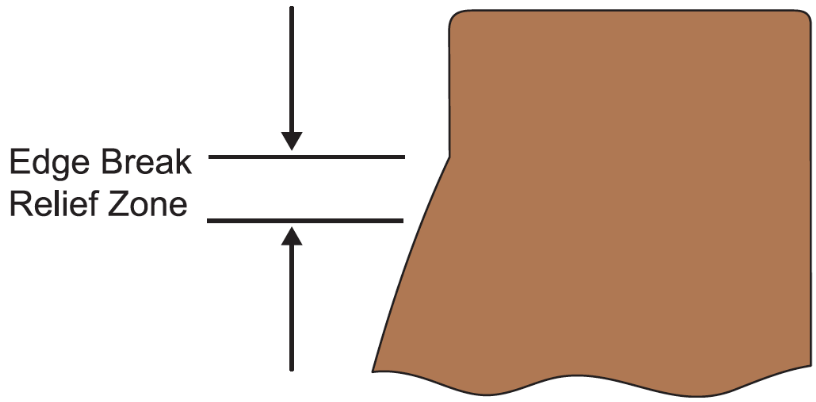
A sharp corner is mechanically much weaker than a rounded or chamfered corner. (Ex. 2001, Milster Decl., ¶ 107.) For example, a Plastics Today article by Glenn Beall explains that a corner with a 0.02-inch radius of curvature can withstand 8 times the impact load of a corner with a 0.01-inch radius of curvature. (Ex. 2007, Beall.) Making extremely sharp corners without chipping the lens is difficult regardless of the manufacturing technique used. (Ex. 2001, Milster Decl., ¶ 107.)

A practical lens design would use an edge shape that permitted oversizing and rounded corners. The importance of oversizing is explained in the Handbook of Optics:

> Surface-tension effects may play a significant role in the accuracy to which a precision optical surface may be molded. Particularly in areas of the part where the ratio of surface area / volume is locally high (corners, edges), surface tension may create nonuniform shrinkage which propagates inward into the clear aperture, resulting in an edge rollback condition similar to that which is familiar to glass opticians. . . . ***These phenomena provide motivation to oversize optical elements, if possible, to a dimension considerably beyond the clear apertures***. A buffer region, or an integrally molded flange provides the additional benefit of harmlessly absorbing optical inhomogeneities which typically form near the injection gate.

(Ex. 1019, Handbook of Optics, Vol. 2 at 34.16; Ex. 2001, Milster Decl., ¶ 108.)

The Field Guide suggests oversizing of around 4-10% for molded plastics:



> Because of the impact of edge break, molders will require the CA size to be smaller than the full optical surface that is molded. The amount of edge relief will depend on the part size, but one millimeter or more in the radial direction is desired for parts of approximately 10 to 25 mm in diameter.
>
> This much relief is often impractical for smaller parts, where it would be a substantial portion of their diameter. In this case, the edge break relief zone will need to scale down with the part size.

(Ex. 2006, Symmons at 103; Ex. 2001, Milster Decl., ¶ 109.)

Dr. Sasián's textbook indicates that even greater degrees of oversizing, 10-20%, are common for traditional polished glass lenses: "A common surface polishing problem is to have the very edge of the surface turned down.

To overcome this figuring problem, there is a tendency to specify a lens diameter larger, say 10–20% larger, than the clear aperture." (Ex. 2004, Sasián at 111; Ex. 2001, Milster Decl., ¶ 110.)

The problem with Dr. Sasián's first modified lens is that the first lens shape leaves no room to oversize or to have rounded or chamfered corners. Given the 0.0394 mm edge thickness and 58.86° slope, the diameter could be increased by less than 0.030 mm before the edge thickness reached zero, i.e., less than 3%. (Ex. 2001, Milster Decl., ¶ 111.) And that assumes that an edge thickness of zero were possible, which it is not. (*Id.*)

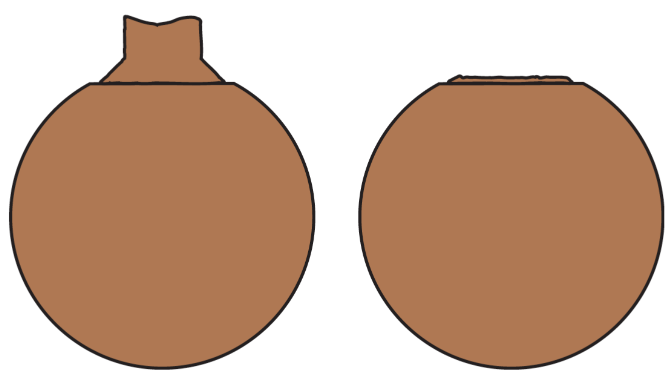
These problems are further compounded by the finite precision of manufacturing techniques. (*Id.*, ¶ 112.) For example, the Beich paper cited by Dr. Sasián provides "rules of thumb" for part tolerances of "± 0.020 mm" for center thickness and diameter, "< 0.020 mm" for the "S1 to S2 Displacement," i.e., the displacement between the halves of the mold forming the front and back surfaces of the lens, and "< 0.010 mm" for "wedge," i.e., the difference in edge thickness from one side of the lens to the other. (Ex. 1007, Beich at 7; Ex. 2001, Milster Decl., ¶ 112.) Tolerances for glass molding are similar. (Ex. 2006, Symmons at 95; Ex. 2001, Milster Decl., ¶ 112.) As the Field Guide notes, "high repeatability from component to component" is an advantage of

molded lenses over other techniques, so other techniques have tolerance issues as well. (Ex. 2006, Symmons at 2; Ex. 2001, Milster Decl., ¶ 112.)

The presence of center thickness variation and "wedge" in the molded parts makes the tiny edge thickness more problematic. (Ex. 2001, Milster Decl., ¶ 113.) A Zemax edge thickness of 0.039 mm becomes a thickness ranging from perhaps 0.015 mm to 0.065 mm in practice. (*Id.*)

Manufacturing tolerances add up. (Ex. 2001, Milster Decl., ¶ 114.) For example, the semi-diameter of the first lens object side in the f-number 2.8 modification of Ogino is 1.0175 mm, while the aperture stop has a semi-diameter of 0.9751 mm, for a difference of only 0.0424 mm. (*Id.*) If the lens diameter has a variation of ± 0.020 mm, the lens has a position offset of 0.020 mm, and the aperture stop (likely made by molding or punching) has similar tolerances, these four variances add under the root sum square rule to yield an error that goes as the square root of the number of errors. (*Id.*; Ex. 2004, Sasián at 116–117.) Even if the first lens is slightly oversized, these additive errors can easily lead to a situation where there is an open gap between the first lens and the aperture, allowing light to leak through and adding a diffuse haze to the image, something that is highly undesirable. (Ex. 2001, Milster Decl., ¶ 114.)

The less-than-hair's-width edge of the first lens causes at least two further problems. (Ex. 2001, Milster Decl., ¶ 115.) First, as explained in Symmons, the injected liquid comes into the mold via runners from the side. (*Id.*) After the part is formed, these now-solid runners must be removed: "It is then cut from the runner/gate system in a process known as degating. The degating process is not perfect and results in residual material being left on the edge of the part. This remaining plastic is called gate vestige." (Ex. 2006, Symmons at 100.) This means that the edge has to be thick enough to provide room for the liquid to flow into the mold and also needs to have space outside the clear aperture to accommodate the imperfect cut of the gate vestige:



(Ex. 2006, Symmons at 100; Ex. 2001, Milster Decl., ¶ 115.)

Bareau recognizes this problem when it refers to "element edge thicknesses shrinking to the point where the flow of plastic is affected." (Ex. 1012, Bareau at 1; Ex. 2001, Milster Decl., ¶ 116.) The tiny edge thickness of Dr.

Sasián's modified lens simply does not have enough room to allow for proper flow of the liquid or to accommodate runners and degating. (Ex. 2001, Milster Decl., ¶ 116.)

The microscopic edge also poses a major problem for mounting the lens element. (Ex. 2001, Milster Decl., ¶ 117.) Any extension or flange of this lens must have at least a portion that is as thin as the edge thickness of the clear aperture, i.e., 0.0394 mm. (*Id.*) Such thin flanges will be difficult to form and regardless of how they are made will be vulnerable to chipping and cracking. Indeed, the Field Guide refers to an injection molded plastic lens with a minimum thickness of "on the order of a few hundred microns" as "extremely small." (Ex. 2006, Symmons 102; Ex. 2001, Milster Decl., ¶ 117.) Dr. Sasián proposes a minimum thickness of a few tens of microns, roughly a factor of ten thinner than what the Field Guide considers "extremely small." (Ex. 2001, Milster Decl., ¶ 117.)

These many issues with thin lens edges lead to a rule of thumb in the Beich paper, which Dr. Sasián himself cites as something that a POSITA would be motivated to follow: the "Center Thickness to Edge Thickness Ratio" should be less than 3:1. (Ex. 1007, Beich at 7; Ex. 1003, Sasián Decl., ¶ 78.) Dr. Sasián's textbook gives a similar rule of thumb, saying "the ratio of

lens central thickness to edge thickness should be larger than 3.2." (Ex. 2004, Sasián at 194.) Dr. Milster's chapter in the Handbook of Optics likewise says to use "a center/edge thickness ration less than 3." (Ex. 2008, Handbook of Optics at 7.11.) By contrast, Dr. Sasián's design has a ratio of 0.6 mm / 0.039375 mm = 15.238, far outside the range of what a POSITA would consider manufacturable. (Ex. 2001, Milster Decl., ¶ 118.)

While that rule of thumb applies to plastic lenses, a POSITA would recognize that the tiny edge thickness is similarly problematic for glass lenses. (Ex. 2001, Milster Decl., ¶ 119.) For example, the Field Guide states that "Very small edge thicknesses (<0.4 mm) should be avoided, as these lenses become very difficult to handle and can chip easily." (Ex. 2006, Symmons at 90; Ex. 2001, Milster Decl., ¶ 119.) This chipping issue is not unique to molded glasses, but will also apply to glass lenses formed other ways. Bareau recognizes this as a general problem for glass lenses when it warns that "[f]or glass elements, the edge thicknesses will become too thin to be fabricated without chipping." (Ex. 1012, Bareau at 1; Ex. 2001, Milster Decl., ¶ 119.) A POSITA would recognize that the edge of Dr. Sasián's lens (0.0394 mm) is too small by a factor of ten for a glass lens. (Ex. 2001, Milster Decl., ¶ 119.)

Also problematic for molded glass is the steep slope of the modified lens, 58.86°. (Ex. 2001, Milster Decl., ¶ 120.) As the Field Guide states:

> The slope of a lens surface should be kept less than 55 deg for PGM. High slopes create difficultly in mold manufacture and testing. Very steep surfaces can be difficult to manufacture and difficult to measure. Precision diamond grinding is limited to just under 55 deg, but the maximum angle varies based on final geometry and manufacturer. Many surface profilometers cannot measure surfaces this steep and begin to lose accuracy at high angles.

(Ex. 2006, Symmons at 94; Ex. 2001, Milster Decl., ¶ 120.)

While this discussion appears in the section on glass molding, each of these problems applies equally to molding plastic and indeed to almost any manufacturing technique. (Ex. 2001, Milster Decl., ¶ 121.) For example, Bareau states that for plastic molding, "the maximum slope that can be diamond-turned in mold inserts and measured in either the lens or the mold is around 45 degrees." (Ex. 1012, Bareau at 8; Ex. 2001, Milster Decl., ¶ 121.) A POSITA would recognize that the 58.86° slope in Dr. Sasián's modified lens is not practical. (Ex. 2001, Milster Decl., ¶ 121.)

As this section shows, the first lens in Dr. Sasián's f-number 2.8 modification of Ogino requires unrealistic manufacturing tolerances, poses practical difficulties in manufacturing, will be vulnerable to chipping and cracking, and will suffer from significant optical defects. (*Id.*, ¶ 122.) A POSITA who had

read Dr. Milster's chapter or Dr. Sasián's book would recognize that it violates manufacturing rules of thumb. (*Id.*)

Both the '897 patent and Ogino depict lenses of the type of the POSITA would actually consider manufacturable, with curved surfaces that are oversized beyond the clear apertures and with relatively thick edges that facilitate accurate manufacture and mounting:

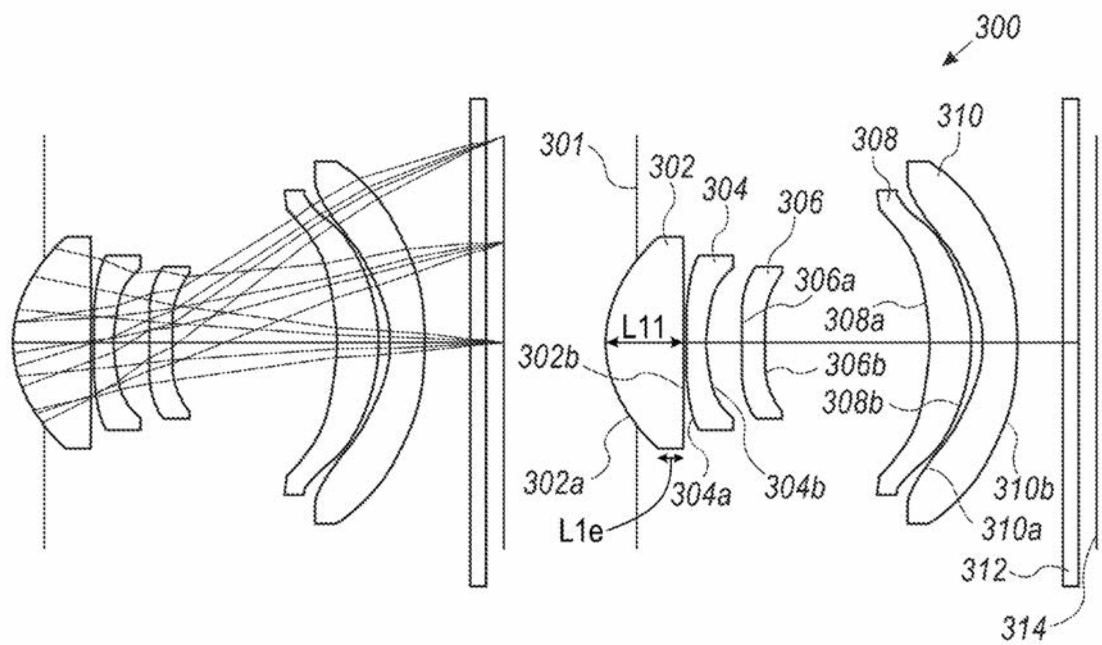
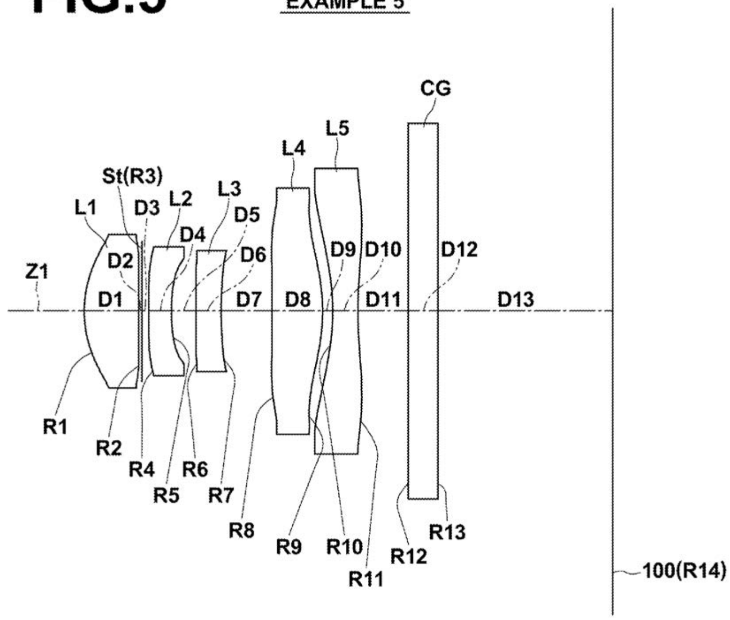


FIG. 3A

FIG.5 EXAMPLE 5



(Ex. 1001, ’897 patent, Figure 3A; Ex. 1005, Ogino, Figure 5; Ex. 2001, Milster Decl., ¶ 123.)

As noted above, the POSITA would not be motivated to reduce the f-number of Ogino Example 5 in the first place, because Ogino has multiple other lens designs that would be more suitable. (Ex. 2001, Milster Decl., ¶ 124.) But, as Dr. Milster explains, “if a POSITA did attempt to modify Example 5, and the best that they could achieve was this unmanufacturable design, unsuitable for use in mobile devices of the type addressed by Ogino and Bareau, the POSITA would wisely have abandoned the effort.” (*Id.*)

B. Ground 3 – Claims 3, 8, 19, and 24 Are Not Obvious over Ogino in view of Bareau and Kingslake

Apple and Dr. Sasián propose a further modification to Ogino Example 5 to satisfy the limitations of claims 3, 8, 19, and 24. These claims add two limitations that are not satisfied by the first modification to Ogino: an image-side surface diameter between 2.3 mm and 2.5 mm for the first lens element (claims 3 and 19) and a convex image-side surface (claims 8 and 24). (Ex. 2001, Milster Decl., ¶ 125.)

The image-side surface diameter of the first lens element in the first modification of Ogino is 2×0.98943 = 1.97886 mm, outside the range required by claims 3 and 19. (Ex. 2001, Milster Decl., ¶ 126.) This image-side surface is also concave, as shown by the positive value of the radius of curvature (252.97534) in Dr. Sasián's lens prescription. (Ex. 1003, Sasián Decl. at 107; Ex. 2001, Milster Decl., ¶ 126.) The fact that the first lens element has a concave image-side surface is a feature of every example in Ogino and is described by Ogino as a defining feature of its invention. (Ex. 2001, Milster Decl., ¶ 126.)

Ogino explains that its invention uses a first lens that "has a positive refractive power and has a meniscus shape which is convex toward the object

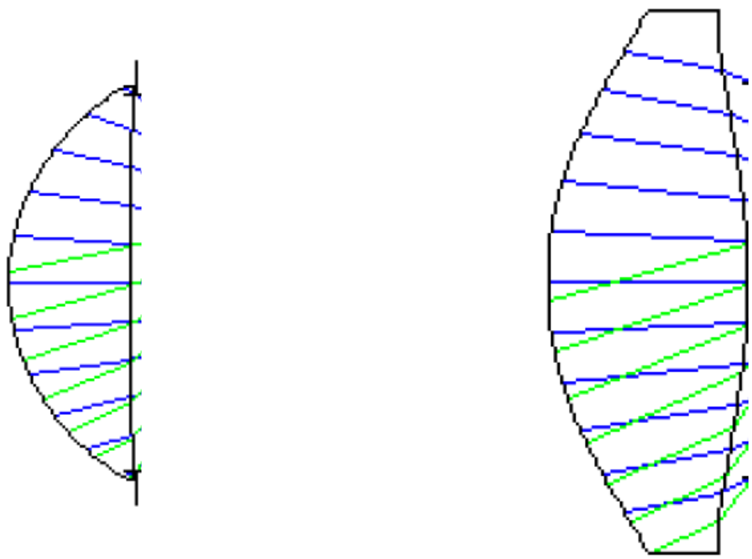
side." (Ex. 1005, Ogino, Abstract, 13:5:10.) Ogino explains its reason for including this feature:

> by making the first lens L1, which is a lens closest to the object, have a positive refractive power and have a meniscus shape which is convex toward the object side in the vicinity of the optical axis, the position of the rear side principal point of the first lens L1 can be set to be close to the object, and ***thus it is possible to appropriately reduce the total length***

(Ex. 1005, Ogino at 7:31–37; Ex. 2001, Milster Decl., ¶ 127.)

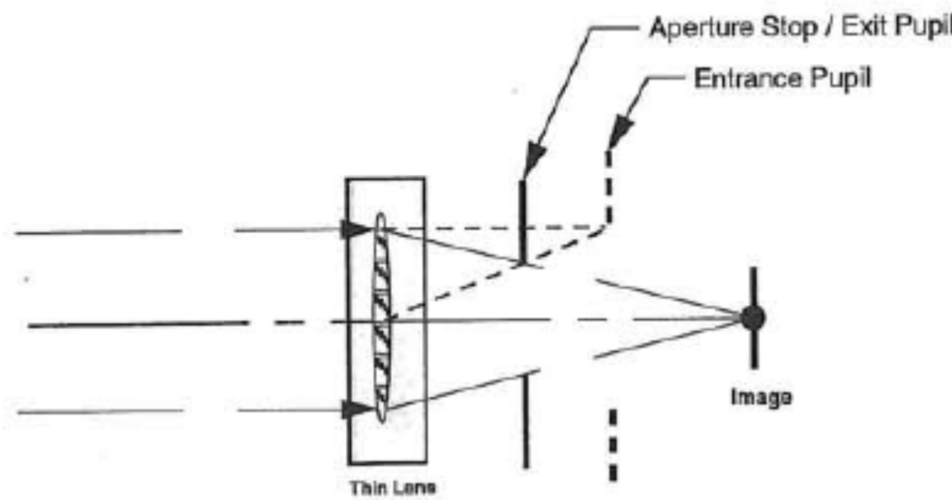
A "meniscus" shape is one that is convex on one side and concave on the other, meaning that a meniscus lens that is convex toward the object side necessarily is concave toward the image side. (Ex. 2001, Milster Decl., ¶ 128.) Dr. Sasián explains how the meniscus lens convex toward the object side in each of Ogino's examples has a concave image-side surface in his analysis of claim 6. (Ex. 1003, Sasián Decl. at 63–66; Ex. 2001, Milster Decl., ¶ 128.)

So, in order to satisfy these limitations of claims 3, 8, 19, and 24, Dr. Sasián had to substantially change the shape of the first lens element, making it much larger, and changing the image side from concave to convex, among other changes:



(Ex. 1003, Sasián Decl. at 104 and 108; Ex. 2001, Milster Decl., ¶ 129.) Indeed, every single parameter of this lens element was changed except for the lens material. (Ex. 2003, Sasián Depo. at 48:15–24; Ex. 2001, Milster Decl., ¶ 129.)

If the goal is to increase the image-side surface diameter to be greater than 2.3 mm, that can be done in Zemax (or similar software) by increasing the entrance pupil diameter, as increasing the size of the bundle of rays entering the first lens element more-or-less mechanically requires that the first lens element, including its image-side surface, become larger:



(Ex. 1016, Walker, p. 61; Ex. 2001, Milster Decl., ¶ 130.)

Likewise, if the goal is to make the image-side surface convex, that can be done by hand. (Ex. 2001, Milster Decl., ¶ 131.) But the fact that these changes are possible does not explain ***why*** a POSITA would make these specific changes, out of all the many parameters of the design they could change. (*Id.*)

Dr. Sasián's declaration and testimony are very unclear on what process he used, let alone why he used that process. (Ex. 2001, Milster Decl., ¶ 132.) The result of his changes has an image-side surface diameter of 2×1.17086 ≈ 2.34 mm and a convex image-side surface. (Ex. 1003, Sasián Decl. at 108; Ex. 2001, Milster Decl., ¶ 132.) The stated reason for the modifications was to further reduce f-number below 2.8. (Ex. 1003, Sasián Decl., ¶¶ 61–64.) Dr.

Sasián cites general statements suggesting lower f-numbers are desirable, but the only specific f-numbers that he points to that are less than 2.8 are the f-numbers in example 1–3 and 6 of Ogino. (Ex. 1003, Sasián Decl., ¶ 62; Ex. 2001, Milster Decl., ¶ 132.)

As explained above, if the goal of a POSITA aware of Ogino was to use a lens with small f-number such as 2.45, the natural and obvious thing to do would be to use one of Ogino's small f-number examples, not to take the example with the largest f-number and modify it beyond recognition. (Ex. 2001, Milster Decl., ¶ 133.) However, even if the small f-number examples in Ogino did suggest to a POSITA that they should reduce the f-number of Example 5, they would not suggest reducing it to be even lower than 2.45. (*Id.*)

According to Dr. Sasián's declaration, the second modification of Ogino has an f-number of 2.12. (Ex. 1003, Sasián Decl. at 108.) This value is consistent with his values of EFL = 5.49 and EPD = 2.59, because 5.49 / 2.59 = 2.12. (Ex. 2001, Milster Decl., ¶ 134.) This suggests that these numbers actually came from some calculation in Zemax or elsewhere and are not simply a typographical error. (*Id.*)

Right after the lunch break during his deposition, Dr. Sasián volunteered that the values on page 108 of his declaration should actually be EPD = 2.239

and f-number = 2.45, based on a file that he found on a backup drive during the break. (Ex. 2003, Sasián Depo. at 58:23–59:16.) Corephotonics made timely objections to this testimony, based on unproduced backup files, and it maintains those objections. (Ex. 2003, Sasián Depo. at 62:11–20; *see* Ex. 2001, Milster Decl., ¶ 135.)

It is similarly unclear how Dr. Sasián obtained a design with a convex image-side of the first lens. (Ex. 2001, Milster Decl., ¶ 136.) The blank box to the right of the radius of curvature for this image-side surface indicates that this value was fixed (and thus that that surface was fixed to be convex) during the run of Zemax that produced the screen capture:

Lens Data Editor

Edit Solves View Help

Surf:Type		Comment	Radius	
OBJ	Standard		Infinity	
1	Even Asph..		1.606950699	
2	Even Asph..		-2.94377806	
STO	Standard		Infinity	
4	Even Asph..		-18.7883600	

(Ex. 1003, Sasián Decl. at 111; Ex. 2003, Sasián Depo. at 49:20–50:16; Ex. 2001, Milster Decl., ¶ 136.)

So, in this particular Zemax optimization, the output had a convex image-side of the first lens because that property had been fixed in place. (Ex. 2001, Milster Decl., ¶ 137.) Dr. Sasián testified that this value had "most likely" been produced by a Zemax optimizer in an earlier stage of his work. (Ex. 2003, Sasián Depo. at 49:20–50:1.) But he could not remember any of the details of how he had generated those values, answering a series of questions about this with "probably," "perhaps," "I don't remember exactly the sequence," "it appears," "I don't recall," etc. (Ex. 2003, Sasián Depo. at 50:18–53:9.) Nothing in his declaration explains these details, either. (Ex. 2001, Milster Decl., ¶ 137.)

At most, the declaration shows that Dr. Sasián, a highly experienced lens designer with a copy of the '897 patent claims in front of him, was able to create a lens system that completely replaced the first lens of Ogino Example 5 with a very different lens that satisfied claims 3, 8, 19, 24. (Ex. 2001, Milster Decl., ¶ 138.) In the process he ignored Ogino's own teachings about the importance of the meniscus-shaped first lens to reduce the total length. (*Id.*)

However, Dr. Sasián does not explain why ***he*** did it or how he did it in 2020, let alone why a ***POSITA*** would have been motivated to make these changes years earlier. (Ex. 2001, Milster Decl., ¶ 139.) For example, he does

not cite to any example of a system with a bi-convex lens that would have motivated the POSITA to try this approach, and he doesn't explain any benefits that flow from this change. (*Id.*) Indeed, the only reason he gives for changing the radii of curvature of the first lens at all (let alone flipping one from a concave positive radius to a convex negative radius) is a vague statement that he did it "due to the location of the aperture." (Ex. 1003, Sasián Decl. at 108; Ex. 2001, Milster Decl., ¶ 139.)

Dr. Sasián's declaration shows that a highly-skilled designer, of considerably beyond ordinary skill, could have designed a lens that met claims 3, 8, 19, and 24 if given that specific task. (Ex. 2001, Milster Decl., ¶ 140.) He provides no explanation for why a POSITA would have made the specific changes he made the first lens of Example 5, or why that POSITA would have even started with Ogino's f-number 3.94 lens if her goal were to have a lens with an f-number that matched Ogino's other examples. (*Id.*)

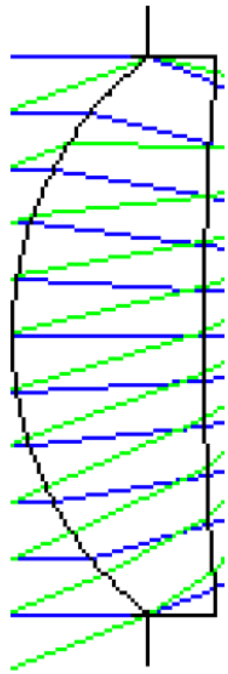
C. Ground 4 – Claims 16 and 30 Are Not Obvious over Chen in view of Iwasaki and Beich

A POSITA would not have been motivated to make the combination proposed by Dr. Sasián for ground 4, for many of the same reasons as explained in the above discussion of ground 2. (Ex. 2001, Milster Decl., ¶ 141.) The combination of Chen, Iwasaki, and Beich uses a first lens taken from Chen's

first example. (Ex. 1003, Sasián Decl., ¶ 74, p. 115; Ex. 1020, Chen, Figure 24.) However, Chen does not specify the diameter or the edge thickness of this lens. (Ex. 2001, Milster Decl., ¶ 141.)

Dr. Sasián suggests that a POSITA would choose a semi-diameter for this first lens (or at least for its object-side surface) of 1.2375 mm, barely 0.004 mm larger than the semi-diameter of the stop, 1.2333 mm. (Ex. 1003, Sasián Decl. at 115; Ex. 2001, Milster Decl., ¶ 142.) He finds that this lens would have a center-to-edge thickness ratio of 2.92, just under the value of 3 required by claims 16 and 30. (Ex. 2001, Milster Decl., ¶ 142.)

This diameter is essentially the smallest that it could be without disrupting other characteristics of Chen that Dr. Sasián relies upon, such as its f-number. (Ex. 2001, Milster Decl., ¶ 143.) The entrance pupil diameter equals the width of the bunch of parallel blue rays entering the lens from the left, shown in Dr. Sasián's ray trace:



(Ex. 1003, Sasián Decl. at 112; Ex. 2001, Milster Decl., ¶ 143.)

As this shows, the bundle, and thus the entrance pupil, extends all the way across the left surface of the lens. (Ex. 2001, Milster Decl., ¶ 144.) Apple has not proposed making the lens smaller, but if it had, the lens cannot be made smaller without reducing the entrance pupil diameter and increasing the f-number. (*Id.*)

Likewise, Apple has not proposed making the lens larger. But, if it had, the largest that the lens semi-diameter could be without increasing the center-to-edge thickness ratio above 3 would be less than 1.249 mm, approximately

0.012 mm larger (less than 1% larger) than Dr. Sasián proposes. (Ex. 2001, Milster Decl., ¶ 145, Appx. § XI.B.)

As explained above, the manufacturing tolerances of lens fabrication do not permit a design such as this. (Ex. 2001, Milster Decl., ¶ 146.) According to Dr. Sasián, a POSITA would have made this lens using injection molded plastic and would have been motivated to choose this lens diameter based on the Beich paper. The Beich paper also says that the tolerance for the diameter of the lens is "± 0.020 mm," and that the displacement between the front surface of the lens and the back surface is "< 0.020 mm." (Ex. 2001, Milster Decl., ¶ 146.)

As noted above, the semi-diameter of the first lens is only 0.004 mm larger than the stop. (Ex. 2001, Milster Decl., ¶ 147.) If the lens is too small by 0.020 mm in diameter (0.010 mm in semi-diameter), this will make the semi-diameter of the first lens ***smaller*** than the semi-diameter of the stop by 6 μm. This is even without taking into account other sources of variation in the diameter of the stop and the alignment of the components. (*Id.*) A first lens smaller than the stop will mean that light will leak and scatter around the lens and cause a haze in the image that is highly undesirable. (*Id.*) For this reason

alone, a POSITA would make the first lens from Chen larger in diameter than Dr. Sasián proposes, something that Dr. Sasián does not consider. (*Id.*)

But even if Dr. Sasián had proposed increasing the size of the lens to be as large as possible while keeping the thickness ratio under 3, the largest possible semidiameter (under 1.249 mm) would be less than 0.016 mm larger than the stop. (Ex. 2001, Milster Decl., ¶ 148.) A POSITA would recognize that this is unacceptable, given the multiple sources of manufacturing variation of the order of 0.010 mm in semi-diameter and adding under the root sum square rule. (Ex. 2004, Sasián at 116–117; Ex. 2001, Milster Decl., ¶ 148.)

The lens is unacceptable even without taking into account the need to oversize "considerably beyond the clear apertures" (Ex. 1019, Handbook of Optics, Vol. 2 at 34.16.) or by around 4–10% (Ex. 2006, Symmons at 103), or the need for room for rounded corners, discussed in connection with ground 2. (Ex. 2001, Milster Decl., ¶ 149.)

Oversizing the 1.2374 mm semi-diameter surface by even 1% (far less than is required in practice) would make it 1.2499 mm in semi-diameter and would make the center-to-edge thickness ratio greater than 3. (Ex. 2001, Milster Decl., ¶ 17, Appx. § XI.B.)

For these reasons, a POSITA would recognize that the combination of Chen, Iwasaki, and Beich proposed by Dr. Sasián would not be a practical lens, based on the very manufacturing rules of thumb in Beich, among other reasons. (Ex. 2001, Milster Decl., ¶ 151.) Even if a POSITA was motivated to make a lens with center-to-edge thickness ratio less than 3, that POSITA would not have been motivated to make the Chen Example 1 lens with that ratio, as proposed by Dr. Sasián. (*Id.*)

IX. CONCLUSION

For the reasons set forth above, Corephotonics respectfully requests that the Board affirm the validity of claims 2, 3, 5, 6, 8, 16, 18, 19, 21–24, and 30 of the ’897 patent.

Dated: February 12, 2021

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CERTIFICATE OF WORD COUNT

I certify that there are 12,190 words in this paper, excluding the portions exempted under 37 C.F.R. § 42.24(a)(1), according the word count tool in Microsoft Word.

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CERTIFICATE OF SERVICE

I hereby certify that "Patent Owner's Response" was served on February 12, 2021 by email sent to:

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UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.,
Petitioner,

v.

COREPHOTONICS, LTD.,
Patent Owner.

Case No. IPR2020-00878
U.S. Patent No. 10,330,897

DECLARATION OF TOM D. MILSTER, Ph.D. PURSUANT TO 37 C.F.R. § 1.68

compact, appropriate for use in mobile devices, and they offer a large focal length (and thus a large degree of image magnification) for their physical size. (Ex. 1001, ’897 patent at 2:6–21.)

40. The lens designs in the ’897 patent are also manufacturable, meaning that they have shapes that can be successfully and repeatably manufactured using the techniques of plastic injection molding that are commonly used for mobile device camera lenses. The ’897 patent designs avoid features such as overly narrow lens edges that make a lens difficult or impossible to manufacture. (Ex. 1001, ’897 patent at 2:35–50.)

41. One of the parameters of a lens design that is discussed in the ’897 patent and claimed in certain claims is the “f-number” or “F#.” The f-number is a property of a lens that relates to how bright the image formed by the lens is. A lens that forms brighter images is sometimes referred to as a “faster” lens, because for a given image sensor (or a given type of film) and focal length, the minimum amount of time required to capture an image varies inversely with the brightness of the image. For a single thin lens, the f number is equal to the focal length of the lens divided by the diameter of the lens:

$$f - number = \frac{f}{diameter}$$

(Walker, Ex. 1016 at 59.)

42. The diameter of the lens determines how much total light is collected per unit time by the lens from a given scene. Under certain approximations, doubling the diameter increases the amount of light collected by a factor of four. The focal length determines the image size on the sensor and thus determines the size of the distribution area of the collected light. Doubling the focal length increases the area illuminated in the image by a factor of four and reduces the intensity of the light in any given part of the image by a factor of four. So, if both the diameter and focal length are doubled, then the effects approximately cancel out, and the brightness of the image at the sensor is left unchanged, although the image is larger. In other words, it is the ratio of the focal length and the diameter that most strongly effects the image brightness.

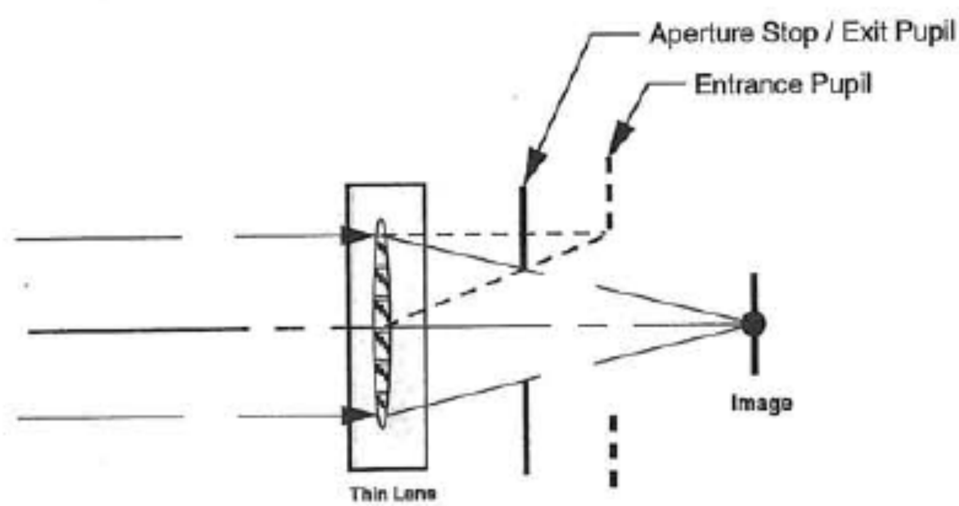
43. Because the diameter is in the denominator, a smaller f-number corresponds to a brighter image for a fixed focal length. In more complicated lens systems with multiple lens elements, such as those at issue in this IPR, the amount of light collected no longer depends on the diameter of a single lens (or of a single lens surface), and the effective focal length (EFL) is a function of the lens elements and their spacings. One definition of f number for such

systems instead uses the diameter of the "entrance pupil" (EPD), meaning that the formula is changed to:

$$f\text{-}number = \frac{EFL}{diameter} = \frac{EFL}{EPD}$$

(Ex. 1003, Sasián Decl. at 58–39.)

44. The concept of the "entrance pupil" is illustrated in the following drawing from Figure 4-2 of Walker:



(Ex. 1016, Walker, p. 61.)

45. As shown here, the entrance pupil reflects the size of the bundle of rays parallel to the optical axis of the lens that can enter the lens, travel through the aperture stop, and reach the image plane. Explained another way, the entrance

pupil "is the image of the aperture stop as seen when looking from the object side of the lens." (Ex. 1016, Walker, p. 60.)

VII. CLAIM CONSTRUCTION

46. Dr. Sasián's declaration states (Ex. 1003, Sasián Decl., ¶¶ 38–39) that he applies two claim constructions for terms that the Board has previously construed in IPRs concerning U.S. Patent No. 9,402,032 and 9,568,712, patents to which the '897 patent claims priority:

> Effective Focal Length (EFL): "the focal length of a lens assembly."
>
> Total Track Length (TTL): "the length of the optical axis spacing between the object-side surface of the first lens element and one of: an electronic sensor, a film sensor, and an image plane corresponding to either the electronic sensor or a film sensor."

IPR2018-01140, Paper 37 at 10–18.

47. I understand that the Board also adopted these same constructions in IPR2019-00030 concerning the '568 patent, which as I discussed above contains the same specification as the '897 patent. IPR2019-00030, Paper 32 at 8, 14–15.

48. I have applied these constructions for the terms "Effective Focal Length" (EFL) and "Total Track Length" (TTL) in the '897 patent claims. For all other terms, I have interpreted them based upon their plain and ordinary

to Dr. Sasián "a POSITA looking to implement optical element specifications using injection molding methods would look to Beich for guidance on limitations and parameters that affect lens manufacturability." (Ex. 1003, Sasián Decl., ¶ 78.)

78. Beich explains that the "unique nature of injection molding demands a very disciplined approach during the component design and development phase." (Ex. 1007, Beich at 2.) The paper describes aspects of the injection molding process, such as the "runner system" of channels that convey molten plastic into the mold insert through the sides of the lens. (Ex. 1007, Beich at 6.) Beich explains that "[o]ptics with extremely thick centers and thin edges are very challenging to mold," and it provides a set of "rules of thumb," including that the center thickness to edge thickness ratio for a lens element should be less than "3:1" and that the lens diameter tolerance is ±0.020 mm. (Ex. 1007, Beich at 7.)

IX. OBVIOUSNESS

A. Ground 2 – Obviousness of Claims 2, 5, 6, 18, and 21–23 over Ogino in view of Bareau

79. According to Dr. Sasián, Ogino Example 5 satisfies each of the elements of claims 1 and 17 of the '897 patent. Dependent claims 2, 5, 6, 18, and 21–23 each add the requirement that f-number be less than 2.9, or in the case

of claim 23 that the f-number equal 2.8. But, Ogino Example 5 has an f-number of 3.94. Ogino Figure 12.

80. Dr. Sasián shows how Ogino Example 5 ***could*** be modified using the Zemax software, to reduce the f-number while leaving all the other characteristics of Example 5 that Apple relies on to satisfy claims 1 and 17 unchanged. However, the fact that Dr. Sasián, a highly skilled and well-regarded lens designer with decades of experience who literally "wrote the book" on the subject could modify Ogino Example 5 in this way in 2020, with the claims of the '897 patent in front of him, does not demonstrate that a lens designer of merely ordinary skill ***would*** have thought to follow this approach in 2013.

81. Bareau suggests that a lens with f-number of 2.8 was desirable for use in a miniature digital camera in 2013. But Bareau also shows that lenses with f-number 2.8 were already commercially available years earlier, in 2006. Ogino itself describes other lenses with f-numbers of 2.45, 2.46, 2.47, 2.64, 3.04. (Ex. 1005, Figures 8–11, 13.) If a POSITA looking at Ogino felt that an f-number of 3.94 was not suitable for their particular application and wanted an f-number of 2.8 instead, that person would naturally look to one of Ogino's other designs, with f-number closer to 2.8, or to one of the hundreds of other miniature lens designs available in the patent literature or in the market. Dr.

to obtain a lens that was ***further*** from Bareau's specifications than Example 6.

88. In addition, a POSITA would have recognized that the lens design that Dr. Sasián created was not manufacturable. That is, the lens has a shape that lens design software such as Zemax will happily perform ray trace calculations on, but that is extremely difficult to construct in a useful physical lens.

89. I understand that Dr. Sasián has previously offered the opinion that a POSITA would know that the lenses described in Ogino would most likely be made of injection-molded plastic. Specifically, Dr. Sasián noted that:

> While Ogino does not specifically indicate that its lens elements can be plastic, a POSITA would recognize that the index of refraction and Abbe number of the lens elements specified in Example 6 of Ogino are within the range of values of plastic materials used for cell phone lenses.
>
> Further lens elements of the sizes and asphericities described in Ogino would preferably be made of plastic via injection molding processes. See Ex.1019, p.34.14 (pdf p.80). A POSITA would also recognize that when designing lens elements for crafting via injection molding, a number of manufacturing realities apply that all promote maximizing the thickness of the lens element at the edge.

(Ex. 2009, IPR2019-00030 Sasián Decl. at 69.)

90. While this earlier statement of Dr. Sasián relates to Ogino Example 6, it applies similarly to Ogino Example 5. For example, the indices of refraction

and Abbe numbers for the materials used in Example 5 are the same as those in Example 6 (Ex. 1005, Ogino, Tables 9, 11), indicating that the same plastic materials were used in both examples.

91. A POSITA would understand that a lens intended for use in a compact camera for a mobile device like Ogino (Ex. 1005, Ogino at 1:7–15) would be made using injection molded plastic. For example, Bareau states that in miniature digital camera modules: "The ***majority of these lenses are all-plastic*** although some incorporate one glass element (usually the front element) for the advantages of high-index refraction and color correction." (Ogino Example 5 does not follow the minority approach of a different non-plastic material for the first lens, as the first and fifth lens both use the same material, Ex. 1005, Ogino, Table 9.) Likewise, Clark (one of the authors of the Bareau article) writing about mobile device camera lenses in 2014 wrote: "Conventional lens designs are multi-element injection molded plastic lenses assembled in a plastic barrel, as they were in 2006." (Ex. 2005, Clark at 3.)

92. To the extent that glass were used in a lens design such as Ogino's, it would also be molded, as molding is the practical approach to making aspheric lenses, such as those in Ogino:

> One of the primary advantages of molded optics has always been the use of aspheric surfaces. Aspheric surfaces are simply

> surfaces that are not spherical. Historically, ***most optical surfaces have been spherical (or flat) due to ease of fabrication and testing with the exception of molded optics***. Aspheric surfaces have long been the standard in molded optics, regardless of process, again due to ease of manufacture. The mold manufacturing process is well suited to aspheric manufacturing, and only having to cut a small number of molds to make a large quantity of optics made an increase in tooling cost trivial when amortized over a molding run.

(Ex. 2006, Symmons at 6.)

93. I have written a chapter in the Handbook of Optics which contains a section on molded glass and plastic optics. (Ex. 2008, Handbook of Optics, Section 7.5.) As I explain there:

> Molded lenses become especially attractive when one is designing an application that requires aspheric surfaces. Conventional techniques for polishing and grinding lenses tend to be time-expensive and do not yield good piece-to-piece uniformity. Direct molding, on the other hand, eliminates the need for any grinding or polishing.

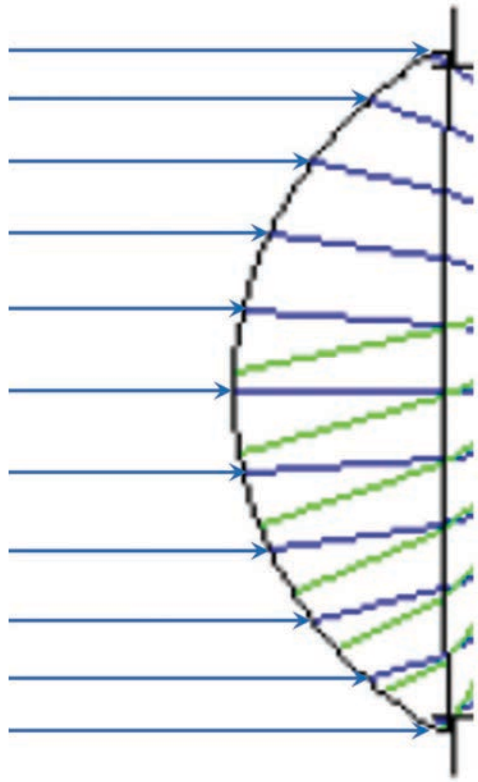
(Ex. 2008, Handbook of Optics, at 7.5–7.6.)

94. The modified lenses discussed by Dr. Sasián have the same indices of refraction and Abbe number as in Ogino's example 5, indicating that these modified lenses would use the same (likely plastic) materials as Ogino. (Ex. 1003, Sasián Decl. at 107, 111; Ex. 1005, Ogino, Table 9.)

95. The main manufacturability problems with Dr. Sasián's f-number 2.8 modification of Ogino concerns the edges of the first lens element:

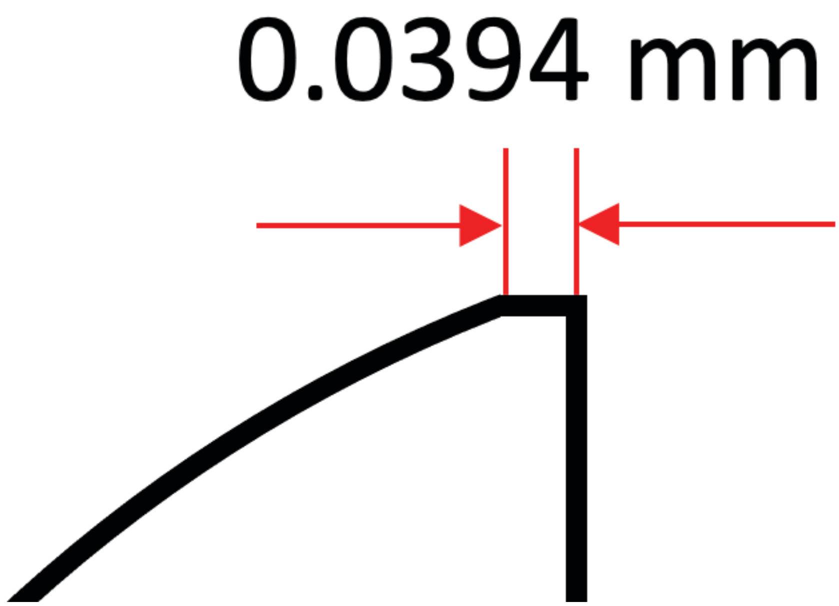
(Ex. 1003, Sasián Decl. at 107.)

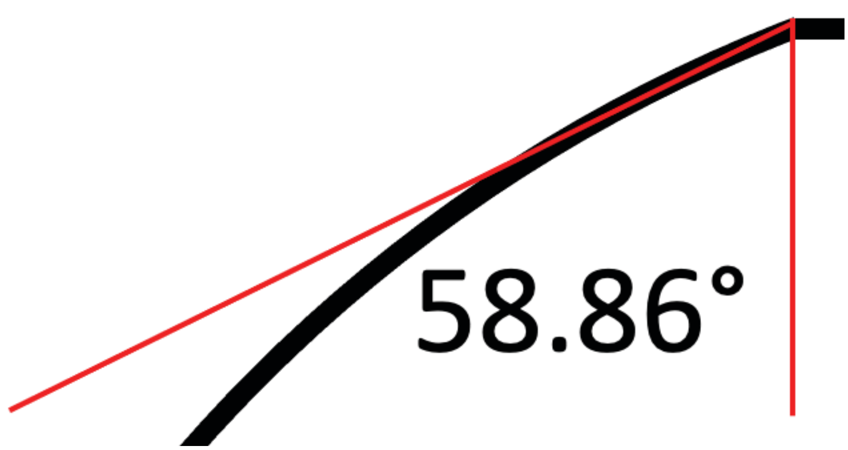
96. The left surface of this of this excerpt is the object side surface of the first lens. The blue rays of this drawing are the rays of the bundle that defines the entrance pupil. As the following drawing illustrates, the light forming these blue rays enters as a bundle of parallel rays from the left before being bent by the lens front surface:



97. The entrance pupil diameter (part of the formula for f-number) is the diameter of this bundle of rays, which in turn is nearly the full diameter of the object-side lens surface in this drawing. In other words, this lens element needs to be at least the diameter shown here in order to achieve the f-number = 2.8 that Dr. Sasián sought to obtain. Put another way, the clear aperture of the first surface needs to be at least as large as shown in this drawing to achieve the f-number Dr. Sasián sought.

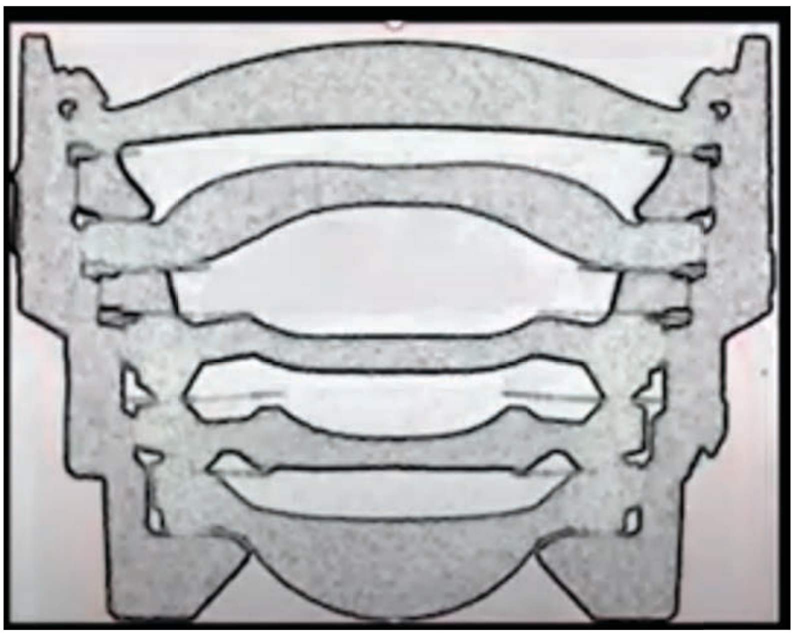
98. The resulting shape has a very narrow edge and a large slope at that edge. According to my calculations, the edge thickness is only 0.0394 mm (or 39.4 microns), and the slope is 58.86°:





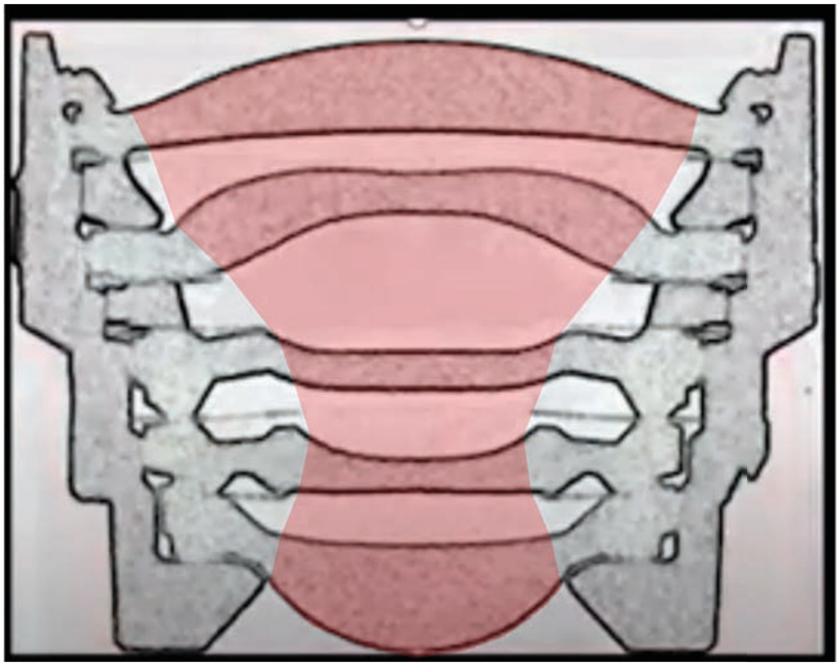
See Appendix Section XI.A.

99. This edge thickness of 39.4 μm (microns) is roughly half the width of a typical human hair, commonly taken to be 75 μm.[11] This is not the edge of a realistic, practical lens. To see why, it is useful to see an actual commercial lens, as in the following X-ray CT image that I had taken as part of my work outside of this IPR[12]:



100. This lens has five plastic elements (gray), with air gaps (white) between them. The bottom of this picture is the object side, and the top is the image side. The portion of the lens that light actually passes through is (very) roughly shown in the red shading below:

[11] https://en.wikipedia.org/wiki/Hair%27s_breadth
[12] A YouTube video of this work is available at https://www.youtube.com/watch?v=E8nE8aBSiJQ.

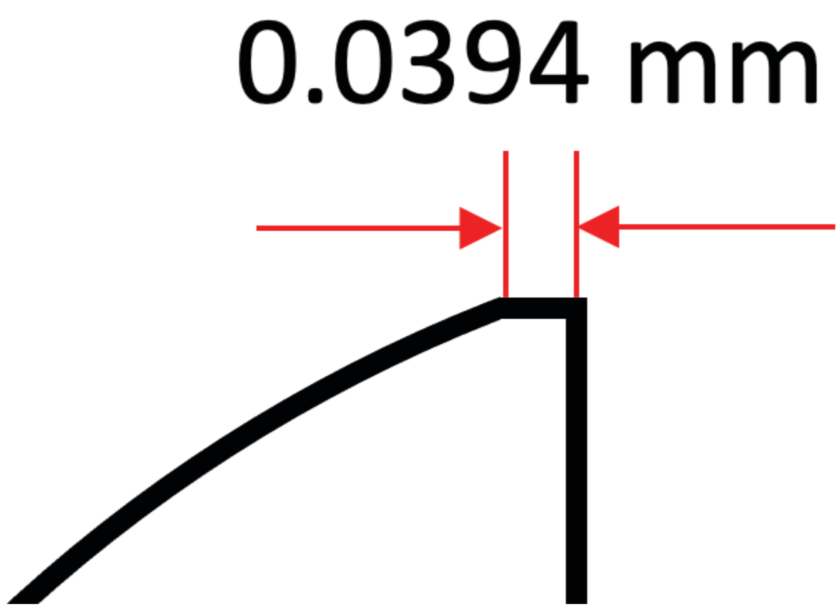


101. The thin black structures protruding from left and right are baffles. There are two important things to note concerning the lens elements in this design. First, each element has a thick mounting flange at its edge, to mount it physically to the roughly cone-shaped lens barrel. Second, the smoothly curved surfaces in the center of each lens element extend beyond the "clear aperture" where light actually passes through the lens. Parts of the curved surfaces are in the shadow of the baffles. In other words, the curved portions of the lens elements are "oversized" relative to their clear apertures.

102. Zemax's ray traces are only concerned with the parts of the lens elements that bend light, i.e., with their clear apertures. The oversized portions and the mounting portions of the lenses are not included in the Zemax designs

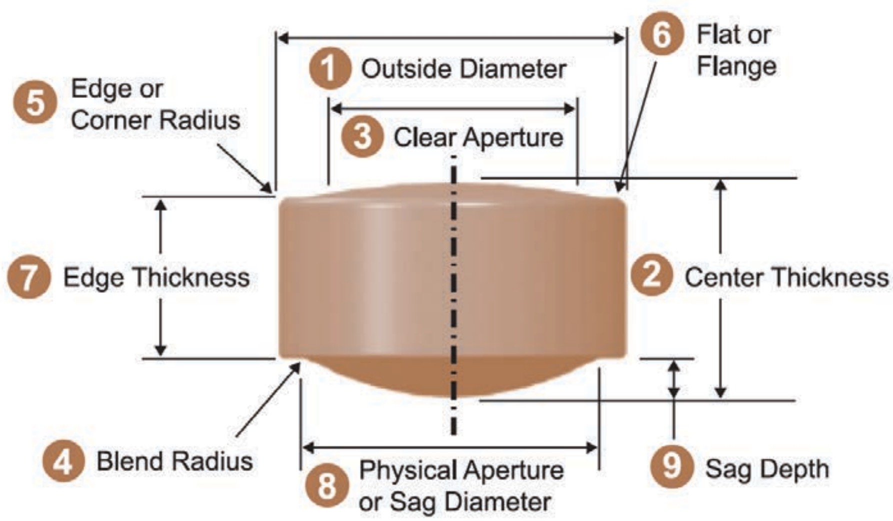
from Dr. Sasián. But a POSITA would understand they need to be there in the actual lens.

103. Oversizing is necessary because a lens cannot be made with perfectly sharp corners and edges. In molded lenses, one reason for this is surface tension of the lens material. If one attempted to inject plastic or glass into a mold with sharp corners such as shown in the Zemax drawing, the liquid would not fill the corners, but would rather form a rounded surface, which would bend light differently than the ideal shape in Zemax:



104. In addition, there are limits to the ability to make molds with such sharp corners in the first place, as the diamond-tipped tools typically used to make them have a finite width and are not infinitely sharp.

105. As explained in the Field Guide to Molded Optics, actual molded lenses have rounded corners:



❺ **Edge radius** or **corner radius** (R_c)

The radius on the outside diameter due to volumetric molding.

(Ex. 2006, Symmons, pp. 87–88.)

106. Even if the surface tension and other limitations of injection molding were not a factor, practical lenses will have rounded or chamfered corners rather than sharp 90° corners, regardless of the technology used to make them.

As Dr. Sasián notes in his textbook, "[i]t is imperative that a bevel, or protective chamfer, is specified to avoid the lens edge easily chipping." (Ex. 2004, Sasián at 112.)

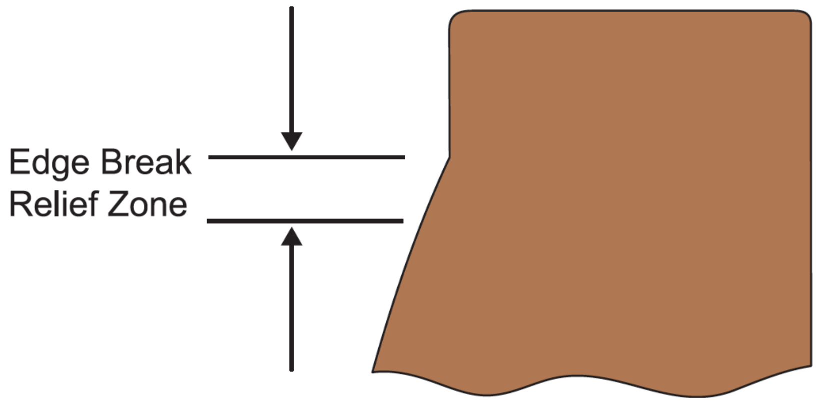
107. A sharp corner is mechanically much weaker than a rounded or chamfered corner. For example, a Plastics Today article by Glenn Beall explains that a corner with a 0.02-inch radius of curvature can withstand 8 times the impact load of a corner with a 0.01-inch radius of curvature. (Ex. 2007, Beall.) Making extremely sharp corners without chipping the lens is difficult regardless of the manufacturing technique used.

108. A practical lens design would use an edge shape that permitted oversizing and rounded corners. The importance of oversizing is explained in the Handbook of Optics (which as explained above contains a chapter by me):

> Surface-tension effects may play a significant role in the accuracy to which a precision optical surface may be molded. Particularly in areas of the part where the ratio of surface area / volume is locally high (corners, edges), surface tension may create nonuniform shrinkage which propagates inward into the clear aperture, resulting in an edge rollback condition similar to that which is familiar to glass opticians. . . . ***These phenomena provide motivation to oversize optical elements, if possible, to a dimension considerably beyond the clear apertures***. A buffer region, or an integrally molded flange provides the additional benefit of harmlessly absorbing optical inhomogeneities which typically form near the injection gate.

(Ex. 1019, Handbook of Optics, Vol. 2 at 34.16.)

109. The Field Guide suggests oversizing of around 4-10% for molded plastics:



> Because of the impact of edge break, molders will require the CA size to be smaller than the full optical surface that is molded. The amount of edge relief will depend on the part size, but one millimeter or more in the radial direction is desired for parts of approximately 10 to 25 mm in diameter.
>
> This much relief is often impractical for smaller parts, where it would be a substantial portion of their diameter. In this case, the edge break relief zone will need to scale down with the part size.

(Ex. 2006, Symmons at 103.)

110. Dr. Sasián's textbook indicates that even greater degrees of oversizing, 10-20%, are common for traditional polished glass lenses: "A common surface polishing problem is to have the very edge of the surface turned down.

To overcome this figuring problem, there is a tendency to specify a lens diameter larger, say 10–20% larger, than the clear aperture." (Ex. 2004, Sasián at 111.)

111. The problem with Dr. Sasián's first modified lens is that the first lens shape leaves no room to oversize or to have rounded or chamfered corners. Given the 0.0394 mm edge thickness and 58.86° slope, the diameter could be increased by less than 0.030 mm before the edge thickness reached zero, i.e., less than 3%. And that assumes that an edge thickness of zero were possible, which it is not.

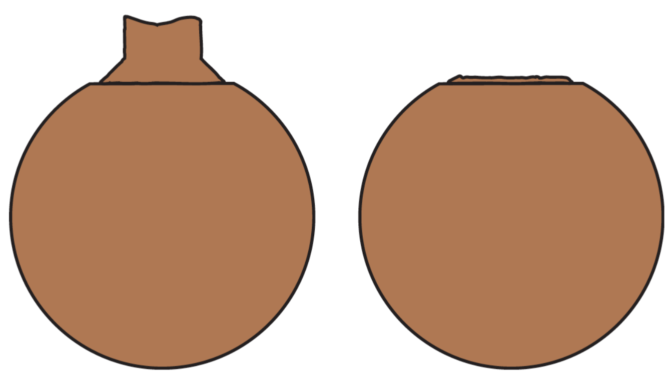
112. These problems are further compounded by the finite precision of manufacturing techniques. For example, the Beich paper cited by Dr. Sasián provides "rules of thumb" for part tolerances of "± 0.020 mm" for center thickness and diameter, "< 0.020 mm" for the "S1 to S2 Displacement," i.e., the displacement between the halves of the mold forming the front and back surfaces of the lens, and "< 0.010 mm" for "wedge," i.e., the difference in edge thickness from one side of the lens to the other. (Ex. 1007, Beich at 7.) Tolerances for glass molding are similar. (Ex. 2006, Symmons at 95.) As the Field Guide notes, "high repeatability from component to component" is an

advantage of molded lenses over other techniques, so other techniques have tolerance issues as well. (Ex. 2006, Symmons at 2.)

113. The presence of center thickness variation and "wedge" in the molded parts makes the tiny edge thickness more problematic. A Zemax edge thickness of 0.039 mm becomes a thickness ranging from perhaps 0.015 mm to 0.065 mm in practice.

114. Manufacturing tolerances add up. For example, the semi-diameter of the first lens object side in the f-number 2.8 modification of Ogino is 1.0175 mm, while the aperture stop has a semi-diameter of 0.9751 mm, for a difference of only 0.0424 mm. If the lens diameter has a variation of ± 0.020 mm, the lens has a position offset of 0.020 mm, and the aperture stop (likely made by molding or punching) has similar tolerances, these four variances add under the root sum square rule to yield an error that goes as the square root of the number of errors. (Ex. 2004, Sasián at 116–117.) Even if the first lens is slightly oversized, these additive errors can easily lead to a situation where there is an open gap between the first lens and the aperture, allowing light to leak through and adding a diffuse haze to the image, something that is highly undesirable.

115. The less-than-hair's-width edge of the first lens causes at least two further problems. First, as explained in Symmons, the injected liquid comes into the mold via runners from the side. After the part is formed, these now-solid runners must be removed: "It is then cut from the runner/gate system in a process known as degating. The degating process is not perfect and results in residual material being left on the edge of the part. This remaining plastic is called gate vestige." (Ex. 2006, Symmons at 100.) This means that the edge has to be thick enough to provide room for the liquid to flow into the mold and also needs to have space outside the clear aperture to accommodate the imperfect cut of the gate vestige:



(Ex. 2006, Symmons at 100.)

116. Bareau recognizes this problem when it refers to "element edge thicknesses shrinking to the point where the flow of plastic is affected." (Ex. 1012, Bareau at 1.) The tiny edge thickness of Dr. Sasián's modified lens simply

does not have enough room to allow for proper flow of the liquid or to accommodate runners and degating.

117. It also poses a major problem for mounting the lens element. Any extension or flange of this lens must have at least a portion that is as thin as the edge thickness of the clear aperture, i.e., 0.0394 mm. Such thin flanges will be difficult to form and regardless of how they are made will be vulnerable to chipping and cracking. Indeed, the Field Guide refers to an injection molded plastic lens with a minimum thickness of "on the order of a few hundred microns" as "extremely small." (Ex. 2006, Symmons 102.) Dr. Sasián proposes a minimum thickness of a few tens of microns, roughly a factor of ten thinner than what the Field Guide considers "extremely small."

118. These many issues with thin lens edges lead to a rule of thumb in the Beich paper, which Dr. Sasián himself cites as something that a POSITA would be motivated to follow: the "Center Thickness to Edge Thickness Ratio" should be less than 3:1. (Ex. 1007, Beich at 7; Ex. 1003, Sasián Decl., ¶ 78.) Dr. Sasián's textbook gives a similar rule of thumb, saying "the ratio of lens central thickness to edge thickness should be larger than 3.2." (Ex. 2004, Sasián at 194.) My chapter in the Handbook of Optics likewise says to use "a center/edge thickness ration less than 3." (Ex. 2008, Handbook of Optics at

7.11.) By contrast, Dr. Sasián's design has a ratio of 0.6 mm / 0.039375 mm = 15.238, far outside the range of what a POSITA would consider manufacturable.

119. While that rule of thumb applies to plastic lenses, a POSITA would recognize that the tiny edge thickness is similarly problematic for glass lenses. For example, the Field Guide states that "Very small edge thicknesses (<0.4 mm) should be avoided, as these lenses become very difficult to handle and can chip easily." This chipping issue is not unique to molded glasses, but will also apply to glass lenses formed other ways. Bareau recognizes this as a general problem for glass lenses when it warns that "[f]or glass elements, the edge thicknesses will become too thin to be fabricated without chipping." (Ex. 1012, Bareau at 1.) A POSITA would recognize that the edge of Dr. Sasián's lens (0.0394 mm) is too small by a factor of ten for a glass lens.

120. Also problematic for molded glass is the steep slope of the modified lens, 58.86°. As the Field Guide states:

> The slope of a lens surface should be kept less than 55 deg for PGM. High slopes create difficultly in mold manufacture and testing. Very steep surfaces can be difficult to manufacture and difficult to measure. Precision diamond grinding is limited to just under 55 deg, but the maximum angle varies based on final geometry and manufacturer. Many surface profilometers cannot measure surfaces this steep and begin to lose accuracy at high angles.

(Ex. 2006, Symmons at 94.)

121. While this discussion appears in the section on glass molding, each of these problems applies equally to molding plastic and indeed to almost any manufacturing technique. For example, Bareau states that for plastic molding, "the maximum slope that can be diamond-turned in mold inserts and measured in either the lens or the mold is around 45 degrees." (Ex. 1012, Bareau at 8.) A POSITA would recognize that the 58.86° slope in Dr. Sasián's modified lens is not practical.

122. As this section shows, the first lens in Dr. Sasián's f-number 2.8 modification of Ogino requires unrealistic manufacturing tolerances, poses practical difficulties in manufacturing, will be vulnerable to chipping and cracking, and will suffer from significant optical defects. A POSITA who had read my chapter or Dr. Sasián's book would recognize that it violates manufacturing rules of thumb.

123. Both the '897 patent and Ogino depict lenses of the type of the POSITA would actually consider manufacturable, with curved surfaces that are oversized beyond the clear apertures and with relatively thick edges that facilitate accurate manufacture and mounting:

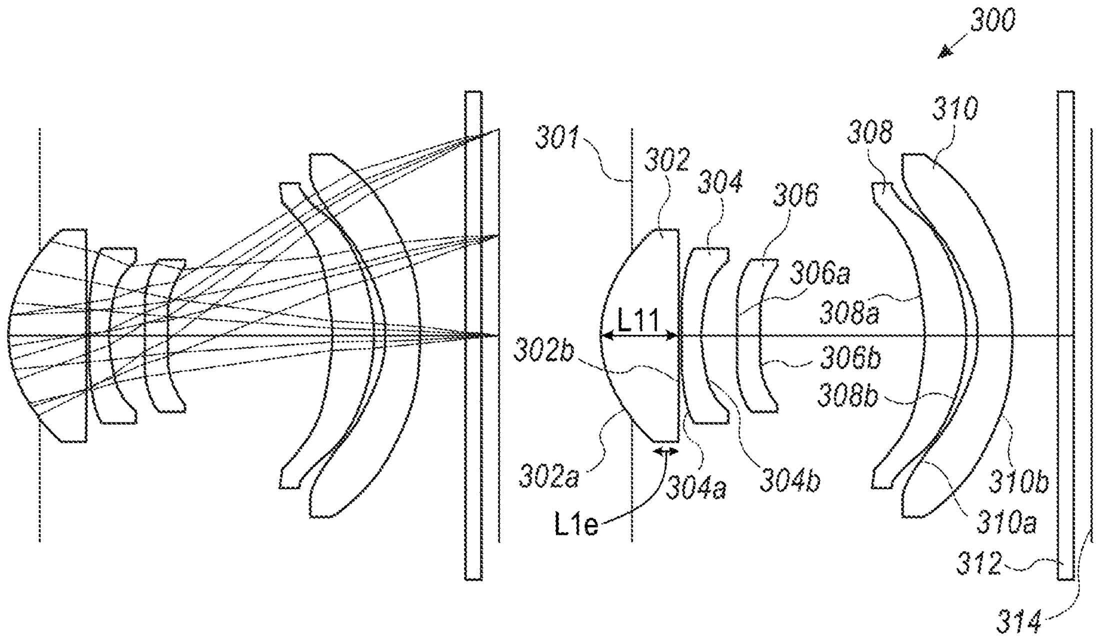
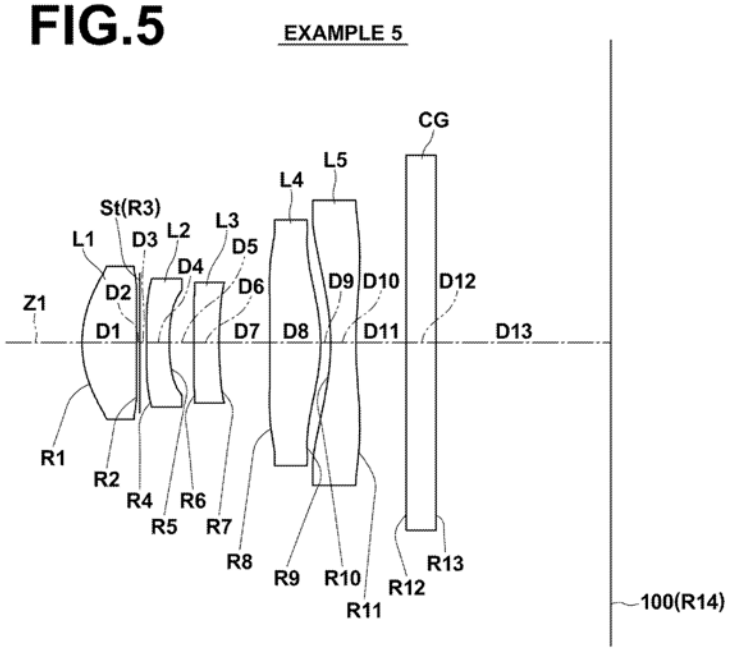


FIG. 3A

(Ex. 1001, ’897 patent, Figure 3A.)

FIG.5



(Ex. 1005, Ogino, Figure 5.)

124. As noted above, the POSITA would not be motivated to reduce the f-number of Ogino Example 5 in the first place, because Ogino has multiple other lens designs that would be more suitable. But, if a POSITA did attempt to modify Example 5, and the best that they could achieve was this unmanufacturable design, unsuitable for use in mobile devices of the type addressed by Ogino and Bareau, the POSITA would wisely have abandoned the effort.

B. Ground 3 – Obviousness of Claims 3, 8, 19, and 24 over Ogino in view of Bareau and Kingslake

125. Apple and Dr. Sasián propose a further modification to Ogino Example 5 to satisfy the limitations of claims 3, 8, 19, and 24. These claims add two limitations that are not satisfied by the first modification to Ogino: an image-side surface diameter between 2.3 mm and 2.5 mm for the first lens element (claims 3 and 19) and a convex image-side surface (claims 8 and 24).

126. The image-side surface diameter of the first lens element in the first modification of Ogino is 2×0.98943 = 1.97886 mm, outside the range required by claims 3 and 19. This image-side surface is also concave, as shown by the positive value of the radius of curvature (252.97534) in Dr. Sasián's lens prescription. (Ex. 1003, Sasián Decl. at 107.) The fact that the first lens element has a concave image-side surface is a feature of every example in Ogino and is described by Ogino as a defining feature of its invention.

127. Ogino explains that its invention uses a first lens that "has a positive refractive power and has a meniscus shape which is convex toward the object side." (Ex. 1005, Ogino, Abstract, 13:5:10.) Ogino explains its reason for including this feature:

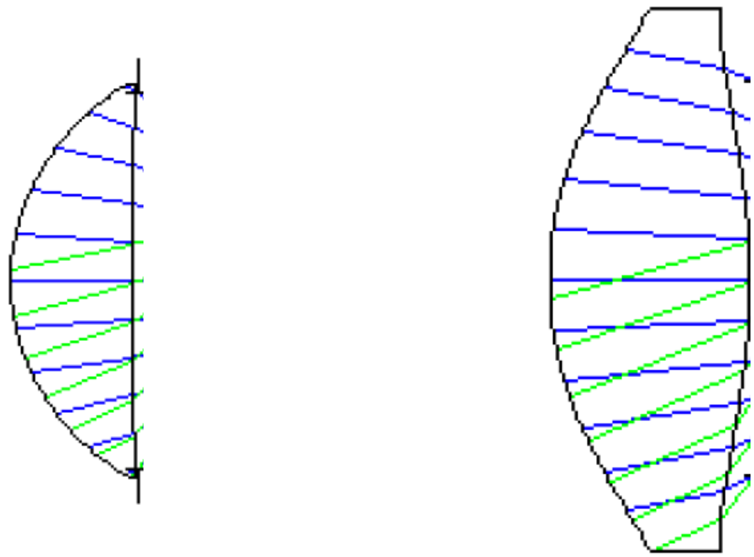
> by making the first lens L1, which is a lens closest to the object, have a positive refractive power and have a meniscus shape

> which is convex toward the object side in the vicinity of the optical axis, the position of the rear side principal point of the first lens L1 can be set to be close to the object, and ***thus it is possible to appropriately reduce the total length***

(Ex. 1005, Ogino at 7:31–37.)

128. A "meniscus" shape is one that is convex on one side and concave on the other, meaning that a meniscus lens that is convex toward the object side necessarily is concave toward the image side. Dr. Sasián explains how the meniscus lens convex toward the object side in each of Ogino's examples has a concave image-side surface in his analysis of claim 6. (Ex. 1003, Sasián Decl. at 63–66.)

129. So, in order to satisfy these limitations of claims 3, 8, 19, and 24, Dr. Sasián had to substantially change the shape of the first lens element, making it much larger, and changing the image side from concave to convex, among other changes:



(Ex. 1003, Sasián Decl. at 104 and 108.) Indeed, every single parameter of this lens element was changed except for the lens material. (Ex. 2003, Sasián Depo. at 48:15–24.)

130. If the goal is to increase the image-side surface diameter to be greater than 2.3 mm, that can be done in Zemax (or similar software) by increasing the entrance pupil diameter, as increasing the size of the bundle of rays entering the first lens element more-or-less mechanically requires that the first lens element, including its image-side surface, become larger:

negative radius) is a vague statement that he did it "due to the location of the aperture." (Ex. 1003, Sasián Decl. at 108.)

140. Dr. Sasián's declaration shows that a highly-skilled designer could have designed a lens that met claims 3, 8, 19, and 24 if given that specific task. He provides no explanation for why a POSITA would have made the specific changes he made the first lens of Example 5, or why that POSITA would have even started with Ogino's f-number 3.94 lens if her goal were to have a lens with an f-number that matched Ogino's other examples.

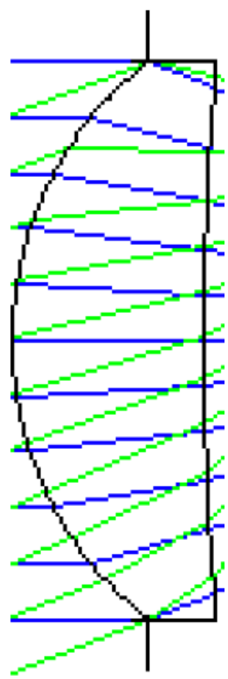
C. Ground 4 – Obviousness of Claims 16 and 30 over Chen in view of Iwasaki and Beich

141. A POSITA would not have been motivated to make the combination proposed by Dr. Sasián for ground 4, for many of the same reasons as I explained in my discussion of ground 2. The combination of Chen, Iwasaki, and Beich uses a first lens taken from Chen's first example. (Ex. 1003, Sasián Decl., ¶ 74, p. 115; Ex. 1020, Chen, Figure 24.) However, Chen does not specify the diameter or the edge thickness of this lens.

142. Dr. Sasián suggests that a POSITA would choose a semi-diameter for this first lens (or at least for its object-side surface) of 1.2375 mm, barely 0.004 mm larger than the semi-diameter of the stop, 1.2333 mm. (Ex. 1003,

Sasián Decl. at 115.) He finds that this lens would have a center-to-edge thickness ratio of 2.92, just under the value of 3 required by claims 16 and 30.

143. This diameter is essentially the smallest that it could be without disrupting other characteristics of Chen that Dr. Sasián relies upon, such as its f-number. The entrance pupil diameter equals the width of the bunch of parallel blue rays entering the lens from the left, shown in Dr. Sasián's ray trace:



(Ex. 1003, Sasián Decl. at 112.)

144. As this shows, the bundle, and thus the entrance pupil, extends all the way across the left surface of the lens. Apple has not proposed making the

lens smaller, but if it had, the lens cannot be made smaller without reducing the entrance pupil diameter and increasing the f-number.

145. Likewise, Apple has not proposed making the lens larger. But, if it had, the largest that the lens semi-diameter could be without increasing the center-to-edge thickness ratio above 3 would be less than 1.249 mm, approximately 0.012 mm larger (less than 1% larger) than Dr. Sasián proposes. See Appendix Section XI.B.

146. As I explained above, the manufacturing tolerances of lens fabrication do not permit a design such as this. According to Dr. Sasián, a POSITA would have made this lens using injection molded plastic and would have been motivated to choose this lens diameter based on the Beich paper. The Beich paper also says that the tolerance for the diameter of the lens is "± 0.020 mm," and that the displacement between the front surface of the lens and the back surface is "< 0.020 mm."

147. As noted above, the semi-diameter of the first lens is only 0.004 mm larger than the stop. If the lens is too small by 0.020 mm in diameter (0.010 mm in semi-diameter), this will make the semi-diameter of the first lens ***smaller*** than the semi-diameter of the stop by 6 µm. This is even without taking into account other sources of variation in the diameter of the stop and

the alignment of the components. A first lens smaller than the stop will mean that light will leak and scatter around the lens and cause a haze in the image that is highly undesirable. For this reason alone, a POSITA would make the first lens from Chen larger in diameter than Dr. Sasián proposes, something that Dr. Sasián does not consider.

148. But even if Dr. Sasián had proposed increasing the size of the lens to be as large as possible while keeping the thickness ratio under 3, the largest possible semidiameter (under 1.249 mm) would be less than 0.016 mm larger than the stop. A POSITA would recognize that this is unacceptable, given the multiple sources of manufacturing variation of the order of 0.010 mm in semi-diameter and adding under the root sum square rule. (Ex. 2004, Sasián at 116–117.)

149. The lens is unacceptable even without taking into account the need to oversize "considerably beyond the clear apertures" (Ex. 1019, Handbook of Optics, Vol. 2 at 34.16.) or by around 4–10% (Ex. 2006, Symmons at 103), or the need for room for rounded corners, discussed in connection with ground 2.

150. Oversizing the 1.2374 mm semi-diameter surface by even 1% (far less than is required in practice) would make it 1.2499 mm in semi-diameter and

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE, INC.,
Petitioner

vs.

COREPHOTONICS, LTD.,
Patent Owner.

Case IPR2020-00877
U.S. Patent 10,288,840

Case IPR2020-00878
U.S. Patent 10,330,897

VIDEO-RECORDED DEPOSITION OF JOSE SASIAN, Ph.D., taken remotely via Zoom at 9:06 a.m., Friday, January 22, 2021, before Theresa JoAnn Phillips-Blackwell, CSR 12700.

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I N D E X

DEPONENT	EXAMINED BY	PAGE
Jose Sasian Ph.D.	Mr. Rubin	6

EXHIBITS

(NONE MARKED)

INSTRUCTED NOT TO ANSWER

PAGE	LINE
60	22

(Remotely via Zoom; Friday, January 22, 2021, 9:06 a.m.)

THE VIDEOGRAPHER: Good morning. We're now on the record. My name is John Hank here today for Barkley Court Reporters. Today is January 22nd, 2021. The time is 9:06 a.m. We are located remotely via videoconferencing technology.

This deposition of Dr. Jose Sasian is being taken today on behalf of the patent owner in the case captioned Apple, Inc., versus Corephotonics, LTD., in the United States Patent and Trademark Office Before the Patent Trial and Appeals Board, Case No. IPR2020-00877, Patent No. 10,288,840 and IPR2020-00878, Patent No. 10,337,897 [sic].

Will counsel for the parties please identify yourselves with city and state where you are appearing from.

DEPOSITION OFFICER: I think you got the patent number wrong again, John.

THE VIDEOGRAPHER: Okay.

MR. RUBIN: Yeah. There's an extra 7, I think, in what you read.

THE VIDEOGRAPHER: All right. The court reporter will correct my audio.

Would counsel please introduce yourselves.

BY MR. RUBIN:
Q. So -- withdrawn.
On this Page 104, Item 6 says, "Image height is 2.06 millimeters."
What is the image height?
A. If you look at the lens figure above and you look at the green beam, it focuses on the rightmost vertical line, which represents the image plane. And the height of the point where it focuses is 2.06 millimeters from the optical exit.
Q. So it's -- so 2.06 millimeters would be the distance between where the blue rays converge at the right-hand side of the drawing and where the green rays converge; is that right?
A. Yes.
Q. Do you know what the corresponding value is in the unmodified Ogino example column?
A. Out of -- out of the top of my head, no.
Q. Do you know if that's something you calculated?
A. I'm not sure I calculated.
Q. I'd like to talk now about the Ogino Example 5 modified for a net number of 2.45, which you discuss in your appendix beginning at Page 108. So you say that you started with Ogino Example 5 at f-number 2.8. So I take it that you did not -- so -- so for the -- well, I

guess, What does it mean that you started with Ogino Example 5 at f 2.8? What is it that you took from that design?
A. The first modified lens has an f-number of 2.8, and so it is a step toward going to a lower f-number. So I started there rather than started from the original -- original lens, which in a sense is starting from the original -- original lens and taking the f 2.85 lens as a step to get to number of 2.45.
Q. And so you then say that you re-optimize with only Lens 1 radii due to the location of the aperture airspaces and aspheric coefficients.
What do you mean when you say that you re-optimize with the L1 radii due to location of the aperture?
A. Let me see if I remember. Yes. The aperture stop is next to the first lens. And -- and as mentioned before, the -- the first lens is a good lens to correct for aberration. So I allowed more degrees of freedom for that lens -- the beam of the faster speed to vary, which were the radii of curvature and the aspheric coefficients and the airspaces.
Q. So why did the -- why did the location of the aperture mean that you wanted to vary the radii curvature in the first one?

A. Because one reason is that you want to make sure that there is enough space to -- to physical -- physically place the aperture stop. So you don't want the surfaces to encroach into the position of the aperture stop. That is one reason.
Q. So turning to the prescription data on Page 111. So the first lens element is defined by the parameters on the rows labeled "1" and "2"; correct?
A. The radii and the thickness are in -- are in -- given in the columns -- well, the surface number and the type of surface are in Columns 1 and 2.
Q. So am I right that the only value from these rows, that is, the rows defining the first lens element -- withdrawn.
Am I correct that the only values on Page 11 from the rows defining the first lens element that match any values in Ogino Example 5 are the index of refraction and the Abbe number of the glass used?
MS. SIVINSKI: Objection. Form.
THE WITNESS: And the question refers to the first lens?
BY MR. RUBIN:
Q. Correct.
A. Yes. I believe so.
Q. So the radii of curvature of the first lens in

this example -- I'm sorry.
The radii of curvature of the first lens in this modified design are different than those in Ogino Example 7 -- I'm sorry -- Example 5; and so are the thicknesses, the conic constant, and the aspheric coefficients?
MS. SIVINSKI: Objection. Form.
THE WITNESS: Just a second. I am looking at my declaration.
Ah, yes. The radii of curvature and the -- are changed.
DEPOSITION OFFICER: Did you say "are changed"?
THE WITNESS: Yes.
BY MR. RUBIN:
Q. So how were those new parameters for the first lens element obtained? Were those generated by Zemax, or were some of them generated a different way?
A. I believe they were given already by Zemax, by the optimizer.
Q. So looking at Page 111, Rows 1 and 2, I don't see any letters next to the radius or thickness values. What -- was there a -- some sort of solve used to produce those values or...
A. They were most likely produced by the optimizer. At some point I may have removed the

Introduction to Lens Design

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CAMBRIDGE
UNIVERSITY PRESS

diameter of the lens is minimized to only allow for enough clearance to properly mount the lens. It is imperative that a bevel, or protective chamfer, is specified to avoid the lens edge easily chipping.

The central lens thickness is measured from surface center to surface center, i.e. along the optical axis. Measuring central thickness requires finding the central portion of the lens, and this contributes to making a precise measurement difficult.

Edge thickness difference, or lens wedge, is measured by supporting the lens in a kinematical mount so that its position is well-defined, and rotating the lens while a micrometer measures the position of the lens edge as the lens rotates. This produces the micrometer reading to oscillate between a minimum and a maximum value, which is the edge thickness difference, called the total indicator runoff. This difference, divided by the lens diameter, gives the lens wedge.

Measuring the radius of curvature of a surface requires an optical bench. Alternatively, optics shops have a collection of test plates with radii of curvature measured with accuracy in an optical bench. Then the lens designer, in a final lens optimization run, fits the radii of curvature of the surfaces of the lens to the radii of curvature of the optics shop test plates. The optics shop tests for radii of curvature errors by observing the Newton rings formed by the test plate and a given lens surface. In this method, the surface radius of curvature is given a tolerance in Newton rings at a given wavelength of light. One Newton ring represents $1/2\lambda$ of sag difference at the edge of the lens between the test plate and the lens surface.

Surface figure, or irregularity, refers to the departure of a surface from the spherical shape, or from the nominal designed aspheric shape. There are many types of figure error, such as surface cylindrical deformation, which would introduce astigmatism aberration, an axially symmetrical error, which would introduce spherical aberration, such as turned down edge, periodic surface errors, which could diffract light and introduce image artifacts, asymmetric surface errors, and others. These figure errors depend on the lens manufacturing method. For example, single point diamond turning produces periodic high spatial frequency figure errors.

A change in the glass index of refraction of a lens element will change the first-order properties of a lens system and will introduce wavefront changes. A change in the glass ν-number of a lens element will change the chromatic correction. To minimize errors, the index of refraction of the glass to be used in the lens manufacture is measured, and the lens is re-optimized to reflect the actual index of refraction. For optical systems with glass elements larger than about 80 mm in diameter, and that are diffraction limited, index of refraction homogeneity within the glass is also a concern.

Paper No.________

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.,
Petitioner,

v.

COREPHOTONICS, LTD.,
Patent Owner

IPR2020-00878
Patent No. 10,330,897

PETITIONER’S REPLY

2. Dr. Sasián used the same techniques that a POSITA would have used to generate the modified lenses of Ogino Ex. 5.

Upon selecting Ogino's Example 5 lens assembly as a suitable starting place, a POSITA would have used well-known techniques to modify the design to achieve a specific design objective. APPL-1003, ¶¶51-58. In particular, reducing the f-number to 2.8 would have been an obvious design objective, as evidenced by Bareau. *See* APPL-1012, pp.3-4. Even Patent Owner acknowledges that "Bareau suggests that a lens with f-number of 2.8 was desirable for use in a miniature digital camera in 2013." Response, p.30.

However, Patent Owner argues that making small changes to Ogino's Example 5 lens to reduce the f-number "is not the approach that a POSITA would actually follow." *See* Response, p.33. Patent Owner takes issue with the minimal nature of the changes, complaining that "[i]n modifying Ogino Example 5, Dr. Sasián kept the number of lens elements, the powers of the lens elements, their thicknesses, and their spacings unchanged, except for a small change to the thickness of the first lens element." Response, p.32.

This, though, is precisely the approach a POSITA would have taken. *See* APPL-1037, ¶11; APPL-1017 (stating that to improve a lens design, "each variable is changed a small amount, called an *increment*, and the effect to performance is then computed") APPL-1017, p.168. Dr. Milster testified that he took a similar

> design teams ***do not know***, and ***do not care***, about the special manufacturing concerns that crop up during the production of polymer lens designs.

APPL-1030, Ex. 2002, p.56 (emphasis original).

In other words, after arguing in a related case (to preserve patentability of a related patent) that manufacturing and lens design are completely separate considerations for a POSITA, Patent Owner now seeks to reject any prior art lens designs based solely on what were previously irrelevant manufacturing considerations. *See* Response, pp.34-55. Patent Owner cannot have it both ways. It cannot argue that a POSITA would not consider manufacturing to preserve patentability for a parent patent then argue the exact opposite to preserve patentability in a child patent relying on the exact same disclosure. Consequently, Patent Owner's arguments here are both conclusory and inconsistent and therefore should carry no weight.

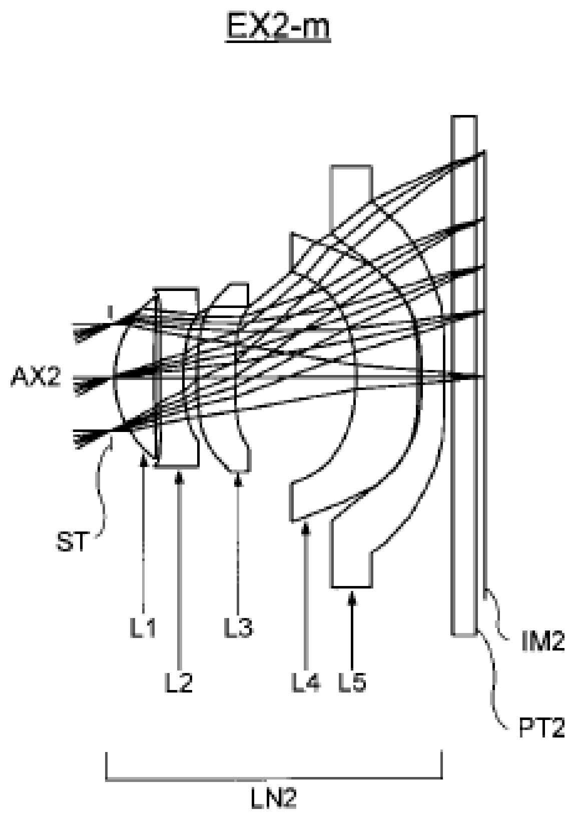
3. Patent Owner's expert admits that a POSITA would have designed lenses for purposes other than mass production manufacturing.

Patent Owner's arguments that lenses should be rejected if they do not meet manufacturing requirements for mass production applications fail to consider that a POSITA would have known of other applications for lens design that do not involve mass production manufacturing. *See* Response, pp.35-53, 66-67. Petitioner notes that the claims of the '897 patent do not include any requirement for mass

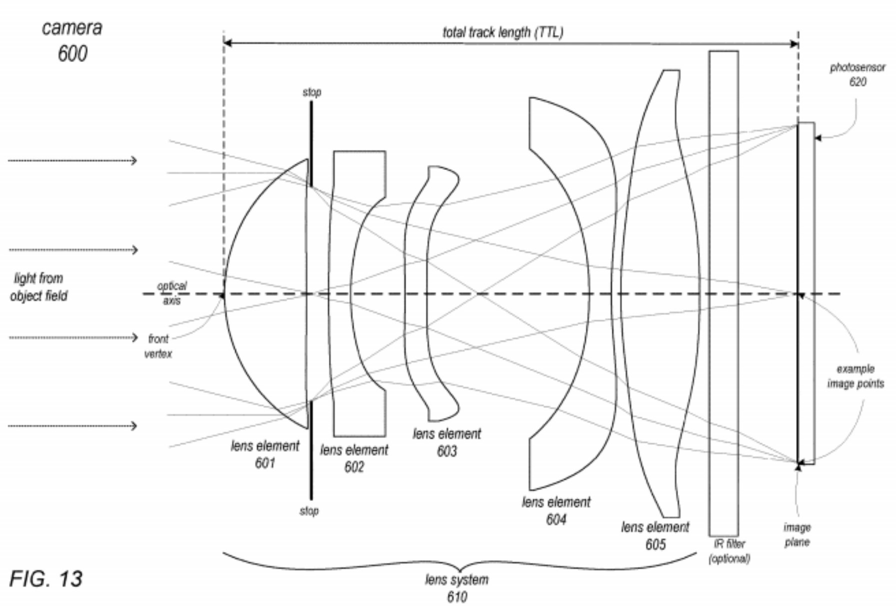
production manufacturing. Moreover, a POSITA would have been motivated to design a lens for limited manufacturing or experimental purposes. APPL-1037, ¶16. These lens designs would not have been subject to the rigorous design requirements of mass-produced injection molding as Patent Owner argues. *Id*.

As Dr. Milster agrees, there are other applications for useful lens designs that are not based on any level of manufacturing: "[a]nd so your question was does a POSITA ever design a lens other than manufacturing and my answer to that is yes." APPL-1028, 173:9-11. He also gave the specific example of an "international lens design conference" as a non-manufacturing application that a POSITA would consider. *Id.*, 172:25. A POSITA therefore would have been motivated to design for other applications that do not involve manufacturing on a large scale, including research and academic applications. APPL-1037, ¶17. The modifications of Ogino's Example 5 presented in the Petition would have been useful for any of these other applications. *Id*.

Moreover, a POSITA would have been aware of other "useful" lenses in the art that have a similarly shaped first lens compared to the modified lens systems presented in the Petition. For example, Japanese Patent Pub. No. JP2013106289 to Konno (APPL-1035) and U.S. Patent No. 10,338,344 to Mercado (APPL-1036) include examples of first lenses with narrow edges as shown below.



APPL-1035, Fig. 11

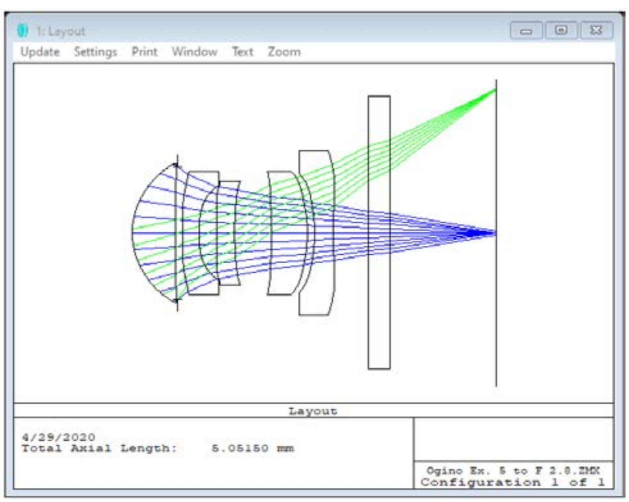


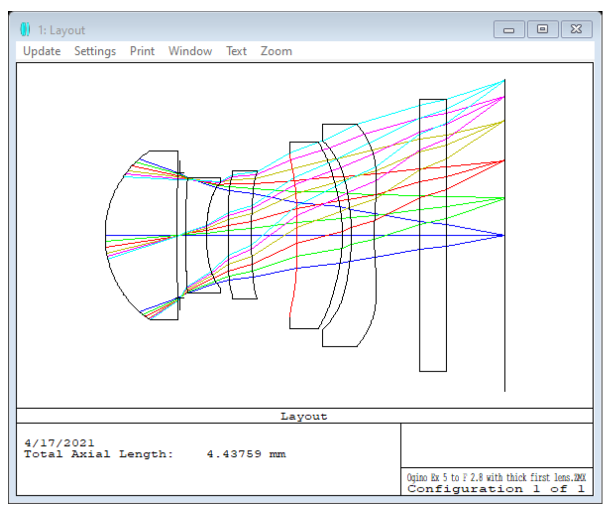
APPL-1036, Fig. 13

subject matter that [applicant] chose to disclose to the public in the written description").

C. A POSITA could have further modified the Example 5 lens to meet Patent Owner's "manufacturing" requirements.

As discussed above, the '897 patent does not require its lenses to be mass-producible as argued by Dr. Milster. However, if a POSITA were to design with the specific further objective to have a lens suitable for such manufacturing, the POSITA had the requisite skill to do so (which still would have met all the limitations of the '897 patent). For example, besides the modified Ogino Example 5 design presented in the Petition ("alternative 1"), Dr. Sasián has provided a further modified design ("alternative 2) that meets Dr. Milster's "manufacturing" requirements, as shown below for comparison:



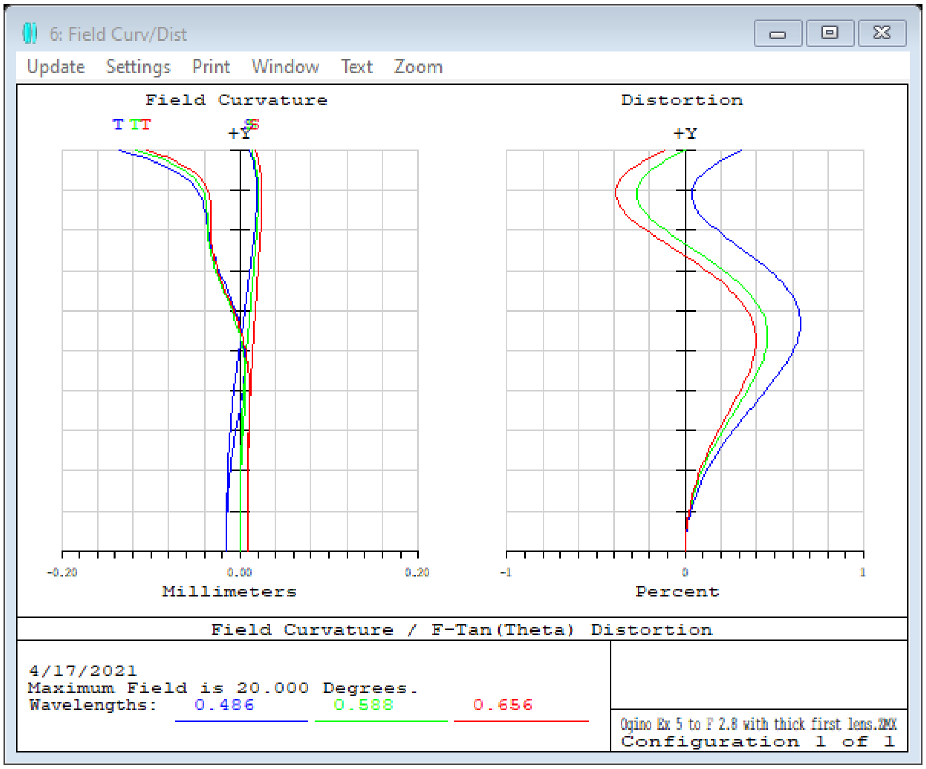


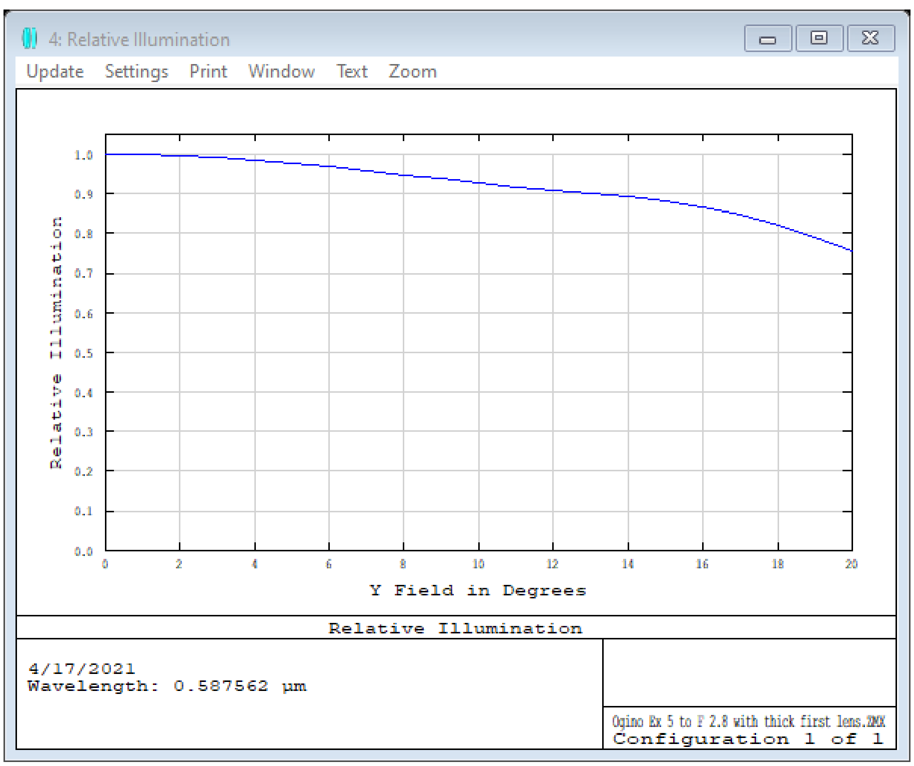
Modified Ogino Example 5, (alternative 1) APPL-1003, p.104.

Modified Ogino Example 5, (alternative 2) APPL-1037, ¶24.

As with the other modifications including alternative 2 offered above, Dr. Sasián proceeded with gradual steps within the level of skill of a POSITA. APPL-1037, ¶25. Specifically, he started with the modified alternative 1 Ogino Example 5 lens assembly and maintained all radii of curvature the same as in the original Ogino Example 5 lens to keep the same lens structure. *Id*. He also maintained all lens thicknesses and spacings except for the thickness of the first lens (that was increased to 0.8 mm) and the distance to the image plane for proper focusing. *Id*. Then, he optimized the lens for minimum spot size and distortion using the aspheric coefficients as variables. *Id*.

As shown above, the modified lens design has a first lens with low center-to-edge thickness, which addresses Patent Owner's manufacturing concerns regarding alternative 1, while still meeting the limitations of claims 2, 5, 6, 18, and 21-23. As shown below, this modified lens design has good optical performance and relative illumination, thereby indicating its desirability to a POSITA. APPL-1037, ¶26.





APPL-1037, Appendix, Figs. 1C-1D.

Accordingly, a POSITA would have had the requisite skill to perform all of these steps if motivated to produce a lens that satisfies Dr. Milster's "manufacturability" requirement. Consequently, claims 2, 5, 6, 18, and 21-23 are obvious in view of Ogino's Example 5 embodiment and Bareau as presented in the Petition. None of Patent Owner's arguments or alleged implicit limitations change the fact that each and every recited limitation is satisfied as explained in the Petition. Petitioner therefore respectfully requests that these claims be found unpatentable and cancelled.

IV. Claims 3, 8, 19, and 24 are obvious over Ogino's Example 5 embodiment in view of Bareau and Kingslake.

A. A POSITA would have been motivated to modify Ogino's Example 5 lens as discussed in the Petition.

Similar to the discussion above, Patent Owner does not allege that the modified lens design presented by Dr. Sasián fails to meet all limitations of claims 3, 8, 19, and 24, or that a POSITA would not have been able to "manufacture" such a design. Instead, Patent Owner argues that a POSITA would not have changed the shape of the first lens from mensiscus to any other shape based on Ogino's teaching that it has a meniscus first lens. Response pp.56-58.

Patent Owner made similar arguments in IPR2018-01140 for the related patent U.S. 9,402,032 ("the '032 patent"), where Dr. Sasian presented a modification of Ogino's Example 6 lens assembly with the second lens changed

from meniscus to biconcave. *See* APPL-1032, Paper 2 at 44. There, Patent Owner argued that "Ogino's own disclosure teaches a POSITA away from modifying the biconcave shape of the second lens." APPL-1033, Paper 14 at 34-35. This argument was rejected by the board in the Final Written Decision: "[w]e agree with Petitioner that Ogino does not require that the second lens is biconcave. We do not find disclosure in Ogino that would have the effect of discrediting or discouraging the use of a meniscus shaped lens." APPL-1034, Paper 37 at 35. Patent Owner's arguments regarding the shape of the first lens in this proceeding should be similarly rejected.

Similarly here, a POSITA would have understood Ogino's teachings about a meniscus-shaped first lens as simply describing its lens designs, not establishing a requirement for or discouragement against modification. APPL-1037, ¶30. A POSITA would not have been constrained by any such teachings in modifying Ogino's examples to satisfy the POSITA's purpose. *Id*. This is supported by the fact that changing the curvature of surfaces within a lens system is a well-known improvement technique that POSITAs regularly consider. *See* APPL-1005, 16:11-19; APPL-1006 at 25-37; APPL-1023, 86:16-23, 97:7-12. In fact, Ogino itself states that its examples "may be modified in various forms" and that "the values of the radius of curvature" can be varied. *See* APPL-1005, 16:11-19. In this case, a POSITA would have been motivated to change the shape of Ogino's Example 5

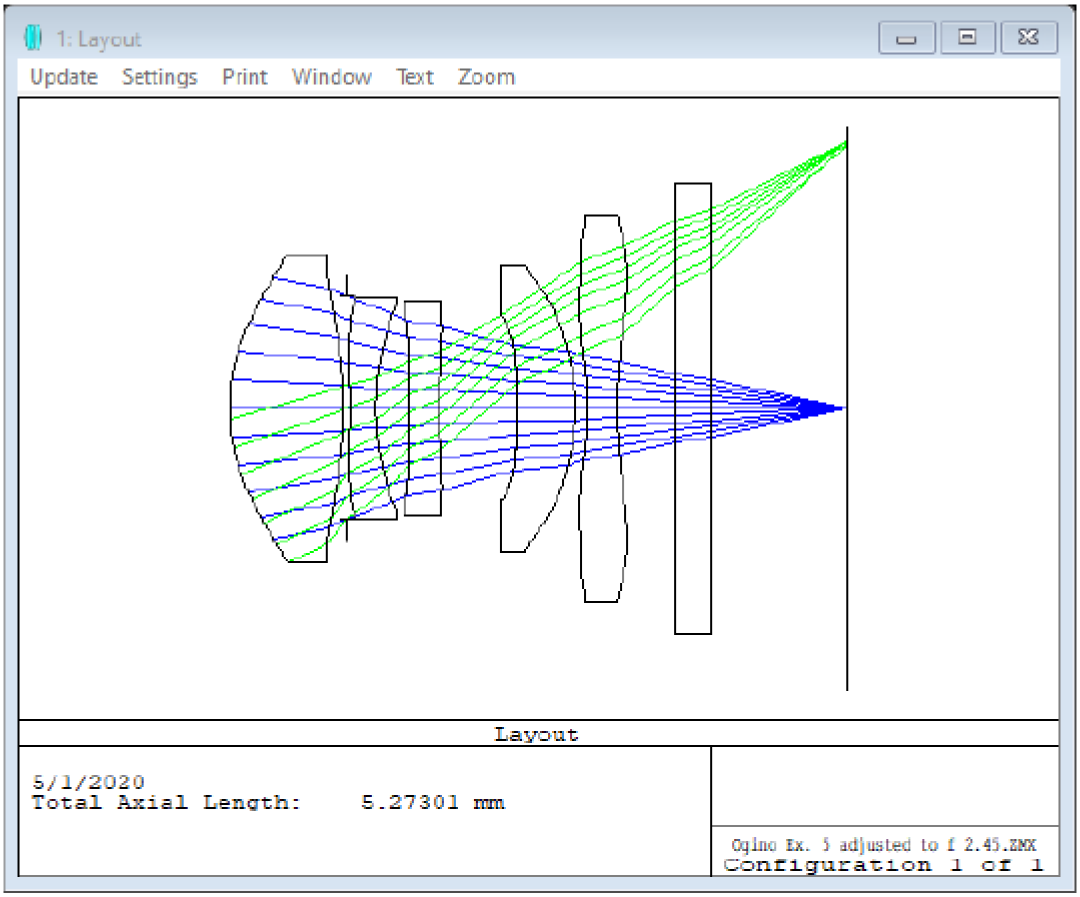
first lens to increase the lens diameter to allow more light to pass through the system while maintaining a focal length similar to the original Ogino Example 5 lens assembly. APPL-1003, p.70.

Patent Owner also argues that although the modified lens is possible, "Dr. Sasian's declaration and testimony are very unclear on what process he used, let alone why he used that process." Response, p.59. Although these steps were included in Dr. Sasian's declaration (*see* APPL-1003, pp.67-71, 108-111), Petitioner again provides the steps Dr. Sasián used to produce the second modified Example 5 lens design, which are gradual and within the level of a skill of a POSITA. As discussed above, a POSITA would have determined Ogino's Example 5 to be a suitable starting place. APPL-1003, p.68. From there, a POSITA would have been motivated to modify the Example 5 lens to reduce the f-number, as taught by Bareau and Kingslake. *Id*. Although f=2.8 is a good target, Ogino's own examples offer simlar designs with smaller F-numbers which a POSITA would have been motivated to experiment with to see if a smaller f-number would also have been attainable for Example 5. *Id*., pp.68-69. A natural target for further reduction would have been f=2.45, which is the lowest F-number offered in Ogino's examples. *Id*., p.69. As provided in the Petition, Dr. Sasián showed that a POSITA would have been successful at reducing the Ogino Example 5 lens assembly to an f-number of 2.45 using the same lens design process that would

have been used by a POSITA. The ray trace of this modification and steps taken to create it (labeled at the bottom right "Ogino Ex. 5 adjusted to f 2.45") were included in the Appendix of the Declaration:

C. Ogino Example 5 modified for F#=2.45 using Zemax (v. 02/14/2011)

1. Fig. 3A – Ray Trace Diagram



Steps for modification:

1) Starting with Ogino Ex. 5 at F#=2.8;
2) Re-optimize lens with only lens L1 radii (due to location of the aperture), airspaces, and aspheric coefficients;
3) Optimize for image quality and a thicker L1 edge for ¼" sensor diagonal.

EFL=5.49; TTL=5.273; EPD=2.59; F#=2.12; f1=2.064 mm; f2-f5 remain unchanged (data calculated for standard wavelength of 587 nm).

APPL-1003, Appendix, p.108.

As Patent Owner notes, the last two lines of this page of the Declaration have a clerical error in the optical data. This is apparent from reviewing other portions of the Petition and Declaration (including the title of the modified lens design in the Appendix as shown above). It is therefore clearly evident that the f-number of the modified design is f=2.45. *See* Petition at 55, 58, 60; APPL-1003, pp.70, 73, 74, 108. For mere clarification, the correct values for the optical data for this design are shown below:

EFL=5.48951
TTL=5.27301
ENPD=2.23915
F/#=2.45
F1=2.063807

Merit Function Editor: 4.334918E-002
Edit Tools View Help

Oper #					Target	Weight	Value	% Contrib
10: TOTR					0.0000000000000	0.0000000000000	5.2730112105151	0.0000000000000
11: EFFL					0.0000000000000	0.0000000000000	5.4859093491707	0.0000000000000
12: EFLY					0.0000000000000	0.0000000000000	2.0638078250490	0.0000000000000
13: EFLY					0.0000000000000	0.0000000000000	-3.166282996806	0.0000000000000
14: EFLY					0.0000000000000	0.0000000000000	-6.952349725125	0.0000000000000
15: EFLY					0.0000000000000	0.0000000000000	2.7359223736945	0.0000000000000
16: EFLY					0.0000000000000	0.0000000000000	-2.453953198435	0.0000000000000

APPL-1037, ¶33, Appendix, Fig. 2B. Petitioner notes that the optical data for this modified lens design is the same that was originally provided in Dr. Sasián's declaration:

4. *Fig. 3D – Prescription Data*

Lens Data Editor

Edit Solves View Help

Surf:Type		Comment	Radius	Thickness		Glass		Semi-Diameter		Conic		Par 0(unuse
OBJ	Standard		Infinity	Infinity				Infinity		0.000000000		
1	Even Asph..		1.406950699	0.975565111		1.54,54.9		1.317712916		-4.07878275	V	
2	Even Asph..		-2.94377806	0.029999192				1.170486227		0.000000000		
STO	Standard		Infinity	0.017175725				0.955456687		0.000000000		
4	Even Asph..		-18.7883600	0.227000000		1.63,23.6		0.551406227		0.000000000		
5	Even Asph..		2.256160000	0.289547566				0.891412894		0.000000000		
6	Even Asph..		506.4558100	0.253000000		1.63,23.6	P	0.889879802		0.000000000		
7	Even Asph..		4.365600000	0.652614911				0.911066103		0.000000000		
8*	Even Asph..		-99.8371500	0.506000000		1.63,23.6	P	0.800000000	U	0.000000000		
9	Even Asph..		-1.70702000	0.100000000				1.219549285		0.000000000		
10	Even Asph..		-2.17464000	0.253000000		1.54,54.9	P	1.673454378		0.000000000		
11	Even Asph..		3.414290000	0.500000000				1.653346230		0.000000000		
12	Standard		Infinity	0.300000000		1.52,64.1		1.851464027		0.000000000		
13	Standard		Infinity	1.169108706	M			1.927481189		0.000000000		
IMA	Standard		Infinity	-				2.395789268		0.000000000		

ar 0(unused)	Par 1(unused)	Par 2(unused)		Par 3(unused)		Par 4(unused)		Par 5(unused)		Par 6(unused)		Par 7(unuse
	0.000000000	0.093561192	V	-0.03529572	V	0.000000000		0.000000000		0.000000000		0.0000000
	0.000000000	0.071236211	V	-0.01583453	V	0.000000000		0.000000000		0.000000000		0.0000000
	0.000000000	0.037677677	V	0.057351146	V	0.000000000		0.000000000		0.000000000		0.0000000
	0.000000000	-9.374E-003	V	-7.293E-004	V	0.000000000		0.000000000		0.000000000		0.0000000
	0.000000000	-0.06391311	V	-0.13033173	V	0.113959785	V	0.000000000		0.000000000		0.0000000
	0.000000000	-0.14858261	V	-0.02520141	V	0.087701329	V	0.000000000		0.000000000		0.0000000
	0.000000000	-0.21251272	V	-0.26430735	V	0.316517423	V	-0.30138838	V	0.000000000		0.0000000
	0.000000000	0.112964355	V	-0.03261618	V	-0.07830211	V	0.044635637	V	0.000000000		0.0000000
	0.000000000	0.302551856	V	-0.13853525	V	6.9798E-003	V	0.013469024	V	-2.683E-003	V	0.0000000
	0.000000000	-0.06055831	V	3.0126E-004	V	6.3498E-003	V	-5.182E-003	V	1.1691E-003	V	0.0000000

APPL-1003, p.111, APPL-1037, ¶34.

Thus, Patent Owner's assertion of impropriety in Dr. Sasián's analysis is misplaced. Further, while Patent Owner appears to maintain an objection about Dr. Sasian's working files, no request was ever made to Petitioner requesting such files and the time for Patent Owner to make such a request has long passed.

Accordingly, Ogino's Example 5 embodiment modified based on the teachings of Bareau and Kingslake would have motivated a POSITA to reduce the f-number as much as possible, with f=2.45 being a natural design goal as provided

in Ogino's other embodiment, thereby rendering claims 3, 8, 19, and 24 obvious. APPL-1003, pp.72-75. Petitioner respectfully requests that these claims be found unpatentable and cancelled.

V. Claims 16 and 30 are obvious in view of Chen's Example 1 embodiment, Iwasaki, and Beich.

A. A POSITA would have been motivated to modify Chen's Example 1 lens as established in the Petition.

Patent Owner's arguments regarding claims 16 and 30 are similar to those discussed above and fail for the same reasons. Specifically, Patent Owner does not dispute that the modified lens assembly presented by Dr. Sasián (which merely replaces the cover glass with a thinner version) meets the claim limitations and would have been possible for a POSITA to produce. Instead, Patent Owner complains that the lens design cannot be oversized to meet various alleged manufacturing tolerances for injection molded lenses. *See* Response, pp.65-67. As discussed above, these manufacturing considerations are not included in claims 16 and 30 or anywhere else in the '897 patent. *See* APPL-1028, 85:20-86:9. Furthermore, a lens designer would not have been bound by these specific manufacturing considerations regardless of the purpose of the lens design, especially with the only change being using a thinner cover glass. APPL-1037, ¶36.

Similar to the discussion above, the modified Chen Example 1 lens design

represents one possible design that meets the limitations of claims 16 and 30. APPL-1003, pp.85-99. Furthermore, it would have been obvious for a POSITA to design for different purposes besides ease of manufacturing that still meet the limitations of claims 16 and 30. APPL-1037, ¶37. And, similar to the discussion in Section III(C) above, a POSITA would have had the requisite skill to design a lens system based on Chen's Example 1 that would meet the manufacturing tolerances cited by Patent Owner, if required. *Id.*

B. The lens designs of the ’897 patent do not meet the manufacturing tolerances posed by the Patent Owner.

As discussed above, Patent Owner did not present evidence that the ’897 patent meets the same manufacturing considerations that it seeks to impose on Dr. Sasián's modified lens designs. *See* Response, p.53; APPL-1028, 98:24-99:4. Not only do the lenses of the ’897 patent fail to meet the manufacturing tolerances proposed by the Patent Owner in regard to claims 16 and 30, two of the three ’897 lens examples *do not even meet the claim limitations*, which claim the only manufacturing considerations arguably recited in the claims – directed to the center-to-edge thickness. *See* APPL-1028, 85:20-86:9. Dr. Sasián's optical analysis of the first lens of Example 3 shows an L11/L1e ratio of 3.054 and the first lens of Example 2 shows an L11/L1e ratio of 3.049, neither of which meet the L11/L1e<3 limitation of claims 16 and 30. *See* APPL-1001, 9:22-25, 10:34-37; APPL-1037,

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

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APPLE, INC.,

Petitioner,

vs.

COREPHOTONICS, LTD.,

Patent Owner.

Case No. IPR2020-00897
U.S. Patent No. 10,324,277

Case No. IPR2020-00896
U.S. Patent No. 10,317,647

Case No. IPR2020-00878
U.S. Patent No. 10,330,897

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Videotaped Deposition of TOM MILSTER

Monday, April 12, 2021

Reported by:

Christina Diaz, CRC, CRR, RMR, CSR

Job No.: 1931

T. Milster

that, you usually step through a sequence where you gradually increase the field of view in steps. You don't just do it all at once. That sort of thing.

Q. So can you describe for me the process of the steps you would take in modifying a lens design, for example, the field of view?

A. Could you give me a specific starting point?

Q. Well, I guess what are the steps that you went through in trying to evaluate the Ogino lenses for which you generated some intermediate designs in this case?

A. Sure. I'd be happy to answer your question. If you could -- it really does depend on the starting point. So if you could be a little bit more specific, it would help me to answer your question.

Q. Okay. So you mentioned that you generated some intermediate designs as part of your analysis in these IPRs. Do you remember which lens design was your starting place when you generated those intermediate designs?

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larger. So there is evidence of oversizing here.

Q. So to make this less assembly manufacturable, would you need to oversize lenses 3, 4 and 5, for example?

A. Yes. Slightly.

Q. So you mentioned earlier that a POSITA in finalizing a lens design might have conversations with people who are specialists in certain aspects of manufacturing thermal issues, for example.

I'd like you to walk me through the process of designing a manufacturable lens and sort of at a high level what steps go into that.

A. Well, the first step is the optical design, and then there's just certain sanity checks on the optical design, can the surfaces be oversized and still meet the performance criteria, looking at the tolerances to make sure that the lenses can work together to provide a high quality image. These are things that can be done in the lens design program. And that includes on -- there's

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probably several levels to that. And if it fails, any one of them, it would negate the manufacturability of a lens.

Then the next steps probably vary depending on the particular company that you're working with. You probably have some approval of going forward with that. And it's not real common to have an optical designer go much beyond that. It usually goes into mechanical design, optical mechanical design, which would include the mounting flanges and the actual design of the molds.

In addition, there's thermal considerations. The ray trace programs have some capability to do thermal analysis. I'm not real familiar with that. What we've done for thermal analysis is quite a bit different where we export the designs into a computer-aided design package like SOLIDWORKS, and then we apply the temperature gradients and things there. It's a lot more general and actually better suited for this type of mechanical analysis. And then we export the result back into the lens design code and

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analyze any defects in performance from that.

And to the degree that a company does that type of -- that level of an analysis is probably up to the company. If you're making a million lenses a month, then probably you'd want to do that, or at least in some form.

And then there's the extension to the actual test of the molded lenses. What I found in my experience is that even with a solid optical design, when you mold the lens, especially in plastic molding, there are many considerations, like the rounding of the surfaces, that are perhaps unexpected and difficult to completely model. You have to have a very, very sophisticated -- let's see, what is it called -- viscoelastic model to properly determine all that. And many of those parameters are specific to the actual plastic material. Many times, it's proprietary material and only the company knows that information that is making the lenses. So if it passes the -- so on the first round of the molding, you produce your

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test cases. And then based, on the results of those lens shapes, you most likely have to go back to another cycle of the mold design to where you compensate for any errors that might be present in the test cases. And then you proceed on. And if the second round is good enough, you iterate until you approach the final desired performance.

Now, in any one of those steps along the way, you can negate a manufacturable design. And there's a really good example of that in Professor Sasian's declaration. And if you give me a moment, I'll turn to that.

(Witness reviewing document).

Now, I think we've talked about this before. And if you look on -- wrong page. Yes. Let's see. Starting on page maybe 44 of my '897 declaration, especially -- it's easy to see on page 45, paragraph 96 of that declaration, the extremely small edge thickness of Professor Sasian's design of the lens 1 in that case. So a POSITA would immediately recognize that this lens would need to be oversized. There's no way it could

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be manufactured the way it is. So at best, it's an intermediate design.

Now, if you oversize the lens, that means you have to make that edge thickness wider. And in order to do that, you would have to change the thickness of the center lens, change the aspheric coefficients. And those changes not only affect that lens, but also the optimization of the whole system.

So this is a case, a really clear case where a POSITA would recognize this is not a lens to go forward with. It failed that test and would have to be completely redesigned. Now, whether that test -- or whether that reconfigured oversized lens would meet the limitations of the claims is unknown because it's just not there. That information is not there.

Q. Would a POSITA know how to oversize a lens like the one described on page 45 of your declaration?

A. There are several things you could do to oversize the lens and I mentioned a few of them. And a POSITA would know how to do

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like what I was involved with with IBM, but that was the timeframe when that really started to take off because of that commercial motivation. And it's the same with the mobile phone cameras. I mean, the reason that the technology is advancing to make these lenses is the commercial motivation. It's not research.

Q. Do you think it's possible that Dr. Sasian's designs could be manufacturable at some point?

A. Well, it depends on what you mean by "manufacturable." I don't think that that lens with the edge thickness that's so narrow would be manufacturable into a cell phone lens. I just don't. And it would require -- for injection molded plastic, no.

Q. And I think you may have spoken on this a little bit, but I can't remember what your answer was.

Is there a particular edge thickness that a POSITA would be looking for, sort of a threshold under which you don't think the design could be manufacturable?

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A. Well, there are lenses that are thin, down to 100 microns or so. But the center-to-edge thickness ratio is not 18 to 1.

Q. Okay.

A. So the answer to your question is it depends. And when your mold is -- has this huge center thickness to edge thickness ratio due to the thin edge, then you have these what they call fill lines as described in the -- I think a good reference for that is the handbook. It shows that pretty clearly, I think.

Q. And is there a rule of thumb center-to-edge thickness ratio that a POSITA would be trying to achieve?

A. I think it's well stated in the three patents that we're looking at here. It's about three to one. That's pretty close to the design goal to be less than that value.

Q. Okay. And would a POSITA eject a design that was over that three to one ratio?

A. Again, the answer to that is it depends. If it's pretty close, then it's probably reasonable considering the other

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.,
Petitioner,

v.

COREPHOTONICS LTD.,
Patent Owner

Declaration of José Sasián, PhD under 37 C.F.R. § 1.68 in Support of Petitioner Reply

considerations were required by any of the claims of ’897 patent, Dr. Milster’s only answer was the center to edge thickness ratio included in claims 16 and 30. *See* APPL-1028, 85:20-86:9. My previous declaration showed how these center-to-edge thickness ratios are disclosed in the prior art without relying on Ogino. APPL-1003, 76-99. Thus, it is clear that the other claims of the ’897 patent do not include any large-scale manufacturing requirements as Dr. Milster seems to imply.

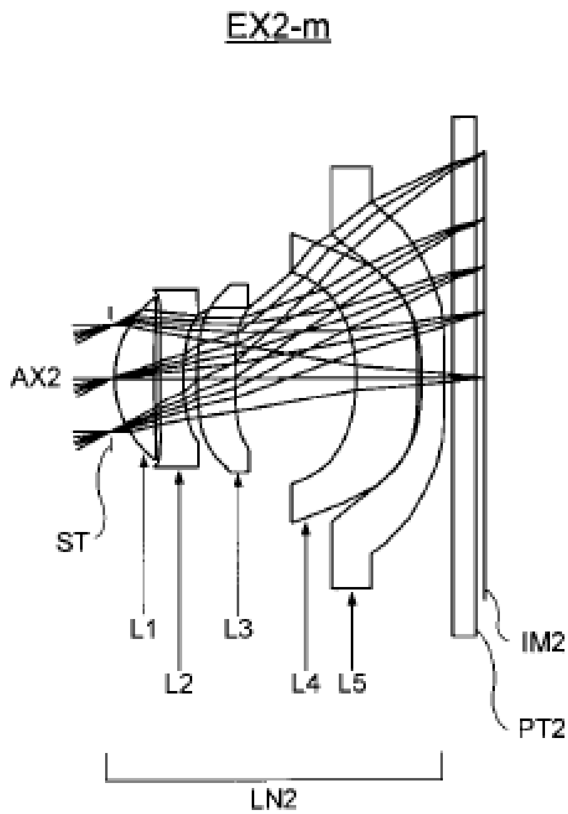
2. Dr. Milster admits that a POSITA would have designed lenses for purposes other than mass production manufacturing.

16. In arguing that lenses should be rejected if they do not meet manufacturing requirements for mass production applications, Dr. Milster’s position in his declaration fails to consider that a POSITA would have known of other applications for lens design that do not involve mass production manufacturing. *See* Ex. 2001 at 88-124. As discussed above, the claims of the ’897 patent do not include any requirement for mass production manufacturing. Moreover, a POSITA would have been motivated to design a lens for limited manufacturing or experimental purposes. These lens designs would not have been subject to the rigorous design requirements of mass-produced injection molding as Dr. Milster argues.

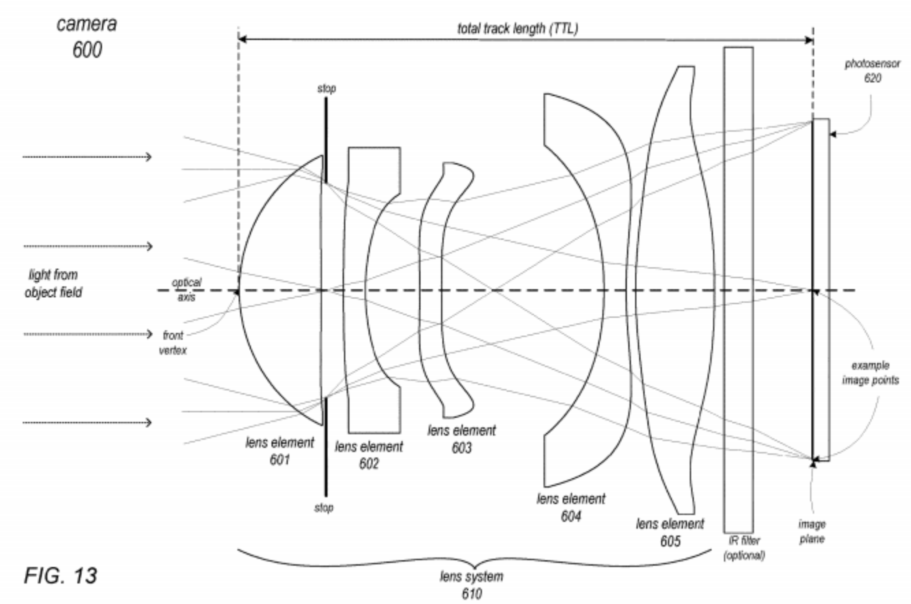
17. During deposition, Dr. Milster also agreed that there are other applications for useful lens designs that are not based on any level of manufacturing: “[a]nd so your question was does a POSITA ever design a lens

other than manufacturing and my answer to that is yes." APPL-1028, 173:9-11. He also gave the specific example of an "international lens design conference" as a non-manufacturing application that a POSITA would consider. *Id.*, 172:25. I agree with Dr. Milster that a POSITA would have been motivated to design for other applications that do not involve manufacturing on a large scale, including research and academic applications. The modifications of Ogino's Example 5 presented in my declaration would have been useful for any of these other applications.

18. Moreover, a POSITA would have been aware of other "useful" lenses in the art that have a similar shape to that of the first lens in the modified lens systems presented in the Petition. For example, Japanese Patent Pub. No. JP2013106289 to Konno (APPL-1035) and U.S. Patent No. 10,338,344 to Mercado (APPL-1036) include examples of first lenses with narrow edges as shown below.



APPL-1035, Fig. 11



APPL-1036, Fig. 13

19. A POSITA would have understood these patented lens designs to have usefulness and purpose, and to be physically producible or able to be adjusted for manufacturing, even if they do not meet the strict large-scale manufacturing considerations argued by Dr. Milster.

3. Manufacturing considerations are preferences, and do not show that lenses cannot be physically produced.

20. Even if a POSITA found the various manufacturing considerations listed by the Dr. Milster to be relevant to the lens design at issue, these considerations would have been understood to be *preferences* and not *requirements*. In fact, Beich (which Dr. Milster relies on) states that "[r]ules of thumb are quick generalizations. They are useful for initial discussions, but the rules can quickly break down as the limits of size, shape, thickness, materials, and tolerances are encountered." APPL-1007, p.7. Even the strictest manufacturing requirements would have therefore been balanced with other considerations. For example, the balance between performance and cost is a common topic in lens design literature. *See* APPL-1012, p. 11 (discussing a hybrid solution incorporating build tolerances, alignment, and depth of field, and that it will be "interesting to see what cost/image quality balance cell phone manufacturers finally select"); APPL-1007, p. 1 (providing "a review of the cost tradeoffs between design tolerances, production volumes, and mold cavitation"). Even in the case where certain manufacturing considerations are important for a particular design or purpose and

are not met, it does not automatically mean that the design is impossible to make. *See* APPL-1007, p.9 (discussing designs that are "more challenging to manufacture" based on unmet manufacturing considerations, but not impossible). And, Dr. Milster has not provided evidence that any lens design, including the lens designs presented in my declaration, would have been impossible to produce.

4. Whether a prior art lens design is "finished" is not called for in the claims of the '897.

21. Dr. Milster further alleges that the modified Example 5 lens is not a finished lens, suitable for "manufacturing." *See* Ex. 2001 at 88. However, the designs in the '897 patent do not satisfy these rigorous manufacturing standards either, nor are these requirements recited in the claims or disclosed in the specification. And, Dr. Milster admitted that he did not analyze the lenses of the '897 patent to determine if they met the same manufacturing standards that he alleges are required for the modified Example 5 designs to satisfy the claims. APPL-1028, 98:24-99:4.

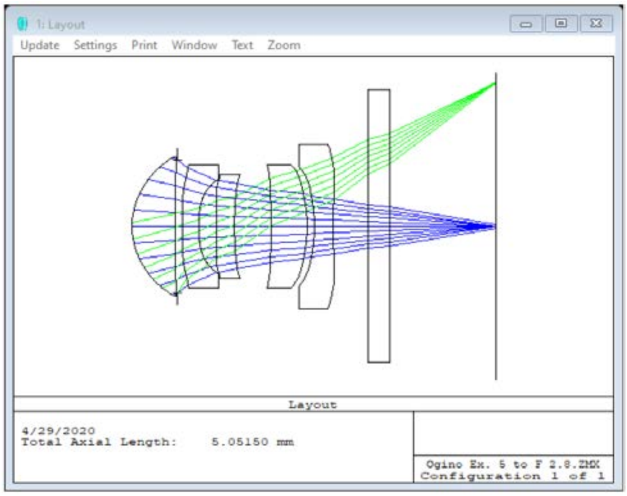
22. If Dr. Milster would have done this analysis, he would have found that the Example 1 lens assembly of the '897 is not suitable for manufacturing (under his owned finished lens theory) for at least the reasons that 1) it is not desensitized and 2) suffers from serious ghost images that are focused on the image plane.

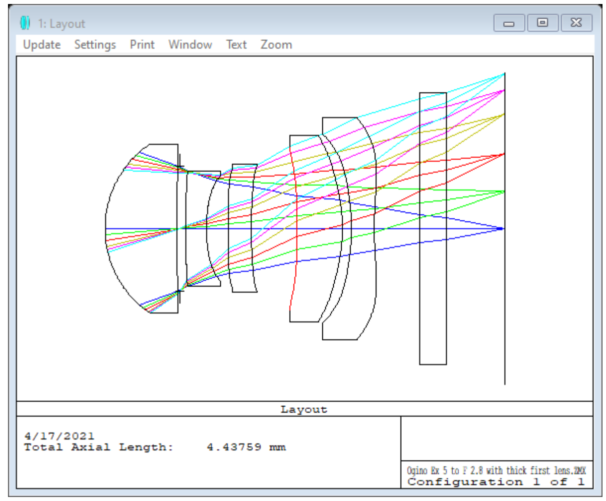
23. Dr. Milster's requirements that a lens system is finished is therefore not implicitly required by the claims in any fashion. Moreover, a POSITA would

have understood that further steps would have been required to prepare the lenses of the ’897 patent for manufacturing, such as conducting a stray light analysis, specifying stray light apertures (glare stops), adjusting for the actual indices of refraction of chosen materials, etc. These steps are also not recited in the claims or even contemplated by the ’897 patent.

C. A POSITA could have further modified the Example 5 lens to meet Dr. Milster’s “manufacturing” requirements.

24. As discussed above, the ’897 patent does not require its lenses to be mass-producible as argued by Dr. Milster. However, if a POSITA were to design with the specific further objective to have a lens suitable for such manufacturing, the POSITA had the requisite skill to do so (which still would have met all the limitations of the ’897 patent). For example, besides the modified Ogino Example 5 design presented in my previous declaration (“alternative 1”), I have provided a further modified design (“alternative 2) that meets Dr. Milster’s “manufacturing” requirements, as shown below for comparison:





Modified Ogino Example 5, (alternative 1) APPL-1003, p.104.

Modified Ogino Example 5, (alternative 2), Appendix, Fig. 1A.

25. As with the other modifications including alternative 2 offered above, I generated this alternative 2 lens by taking gradual steps within the level of skill of a POSITA. *See* Appendix, Fig. 1A. Specifically, I began with the modified Ogino Example 5 lens assembly and maintained all radii of curvature the same as in the Ogino Example 5 lens to keep the same lens structure. *Id*. I also maintained all lens thicknesses and spacings as in the original Ogino lens, except for the thickness of the first lens (that was increased to 0.8 mm) and the distance to the image plane for proper focusing. *Id*. Then, I optimized the lens for minimum spot size and distortion using the aspheric coefficients as variables. *Id*.

26. As shown above, the modified lens design has a first lens with low center-to-edge thickness ratio, which addresses Dr. Milster's manufacturing concerns regarding alternative 1, while still meeting the limitations of claims 2, 5,

6, 18, and 21-23 (as discussed below). As further shown in the Appendix, this alternate 2 modified lens design has good optical performance and relative illumination, thereby indicating its desirability to a POSITA. See Appendix, Figs. 1C-1D.

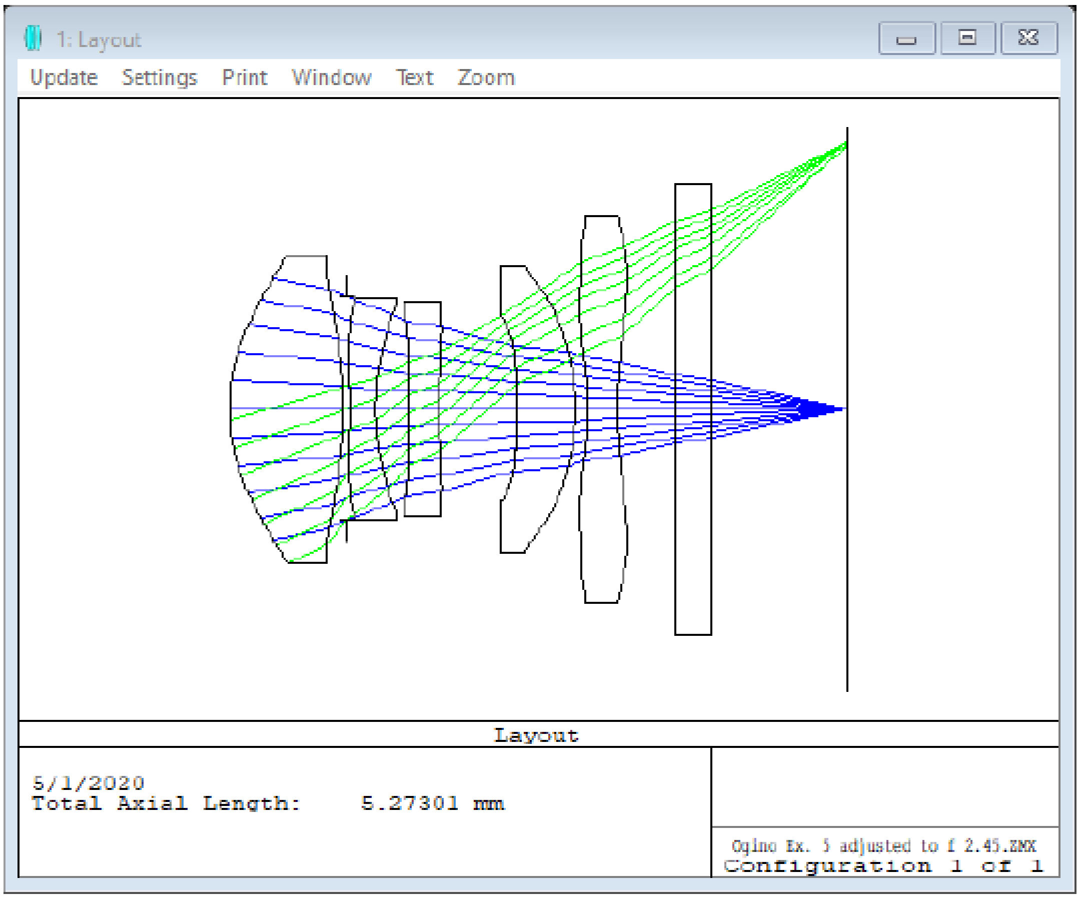
27. Accordingly, it is my opinion that a POSITA would have had the requisite skill to perform all of these steps if motivated to produce a lens (such as the alternative 2 modified lens) that satisfies Dr. Milster's "manufacturability" requirement. Consequently, claims 2, 5, 6, 18, and 21-23 are obvious in view of Ogino's Example 5 embodiment and Bareau. None of Patent Owner's arguments or alleged implicit limitations change the fact that each and every recited limitation is satisfied as explained below:

U.S. 10,330,897	Ogino modified by Bareau to support an F# of 2.8
Claim 2	
[2.0] The lens assembly of claim 1, wherein the TTL is equal or smaller than 6.0 mm and	Ogino discloses this limitation because, as shown in [1.2], the Example 5 lens assembly has a TTL with the cover glass element of 5.273 mm which is less than 6.0 mm. In the alternative 2 modification above where Example 5 supports F#=2.8, the TTL is 4.438 mm. After scaling for a 1/4" sensor (by multiplying by 2.25/1.75), the TTL is 5.7054 compared to the original TTL of 5.273 mm. Thus, the alternative 2 modification of Ogino's Example 5 renders this limitation obvious.
[2.1] wherein the lens assembly has a f-number F# < 2.9.	Ogino's Example 5 modified to support an F# of 2.8 (alternative 2), as taught in Bareau and discussed in detail above, renders this limitation obvious.

modification and steps taken to create it (labeled at the bottom right "Ogino Ex. 5 adjusted to f 2.45") were included in the Appendix of the Declaration:

C. Ogino Example 5 modified for F#=2.45 using Zemax (v. 02/14/2011)

1. Fig. 3A – Ray Trace Diagram



Steps for modification:

1) Starting with Ogino Ex. 5 at F#=2.8;
2) Re-optimize lens with only lens L1 radii (due to location of the aperture), airspaces, and aspheric coefficients;
3) Optimize for image quality and a thicker L1 edge for ¼" sensor diagonal.

EFL=5.49; TTL=5.273; EPD=2.59; F#=2.12; f1=2.064 mm; f2-f5 remain unchanged (data calculated for standard wavelength of 587 nm).

APPL-1003, Appendix at 108.

IV. Claims 16 and 30 are obvious in view of Chen's Example 1 embodiment, Iwasaki, and Beich.

A. A POSITA would have been motivated to modify Chen's Example 1 lens with a thinner cover glass.

36. Dr. Milster's arguments regarding claims 16 and 30 are similar to those discussed above and fail for the same reasons. Specifically, Dr. Milster does not dispute that the modified lens assembly presented in my previous declaration (which merely replaces the cover glass with a thinner version) meets the claim limitations and would have been possible for a POSITA to produce. Instead, Dr. Milster states that the lens design cannot be oversized to meet various alleged manufacturing tolerances for injection molded lenses, such as the ±0.020 mm Rule of Thumb of Beich. *See* Ex. 2001 at 141-147. As discussed above, these manufacturing considerations are not included in claims 16 and 30 or anywhere else in the '897 patent. *See* APPL-1028, 85:20-86:9. Furthermore, a lens designer would not have been bound by these specific manufacturing considerations regardless of the purpose of the lens design, especially with the only change being using a thinner cover glass. As discussed in my earlier declaration, the simple substitution of a cover glass would have been obvious to reduce the total length of a lens system, or if limited options for cover glasses were available. See APPL-1003, ¶74.

37. Similar to the discussion above, the modified Chen Example 1 lens design represents one possible design that meets the limitations of claims 16 and 30. APPL-1003, pp.85-99. Furthermore, it would have been obvious for a POSITA to design for different purposes besides ease of manufacturing that still meet the limitations of claims 16 and 30. Similar to the discussion in Section II(C) above, a POSITA would have had the requisite skill to design a lens system based on Chen's Example 1 that would meet the manufacturing tolerances cited by Dr. Milster, if required.

B. The lens designs of the '897 patent do not meet the manufacturing tolerances posed by Dr. Milster.

38. As discussed above, Dr. Milster did not present evidence that the '897 patent meets the same manufacturing considerations that it seeks to impose on the modified lens designs presented in my declaration. *See* APPL-1028, 98:24-99:4. Not only do the lenses of the '897 patent fail to meet the manufacturing tolerances proposed by Dr. Milster in regard to claims 16 and 30, two of the three '897 lens examples *do not even meet the claim limitations*, which claim the only manufacturing considerations arguably recited in the claims—directed to the center-to-edge thickness. *See* APPL-1028, 85:20-86:9.

39. Fig. 4C in the Appendix shows an optical analysis of the first lens of Example 3 in the '897 patent. With a center thickness of 0.919 mm and an edge

thickness of 0.3009 mm, the first lens has a L11/L1e ratio of 3.054. *See* Appendix, Fig. 4C.

40. Fig. 4B in the Appendix shows an optical analysis of the first lens of Example 2 in the ’897 patent. With a center thickness of 0.898 mm and an edge thickness of 0.2945 mm, the first lens has a L11/L1e ratio of 3.049. *See* Appendix, Fig. 4B. Based on these calculations, a POSITA would have recognized that the Example 2 and 3 lenses of the ’897 patent do not meet the L11/L1e<3 limitation of claims 16 and 30. *See* Appendix, Figs. 4C-4C; APPL-1001, 9:22-25, 10:34-37.

41. Fig. 4A in the Appendix shows an optical analysis of the first lens of Example 1 in the ’897 patent. With a center thickness of 0.894 mm and an edge thickness of 0.298759 mm, the first lens has a L11/L1e ratio of 2.99238. *See* Appendix, Fig. 4A. Therefore, the first lens of Example 1 is the only embodiment that satisfies the L11/L1e<3 limitation. *Id.*

42. According to Dr. Milster, however, this lens is not sufficient to meet the claims because it can only be oversized by 0.000759 mm (far less than the 1% larger tolerance allegedly required, *see* Response at 67) and still be below the claimed ratio. Appendix, Fig. 4A. By Dr. Milster’s own arguments, the Example 1 lens of the ’897 patent (the only embodiment that provides written description support for the center-to-edge thickness) is unacceptable because there is no room for “rounded corners” or “oversizing considerably beyond the clear apertures.” *See*

Ex. 2001 at 149. Consequently, based on the embodiments in the '897 patent, the manufacturing tolerances implicitly required by Dr. Milster are not required by the claims.

43. Thus, the combination of Chen's Example 1 embodiment with the teachings of Iwasaki and Beich renders obvious all of the limitations of claims 16 and 30. APPL-1003, pp.72-75.

Paper No. 19

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.,
Petitioner,

v.

COREPHOTONICS, LTD.,
Patent Owner.

Case No. IPR2020-00878
U.S. Patent No. 10,330,897

PATENT OWNER'S SUR-REPLY

TABLE OF CONTENTS

TABLE OF AUTHORITIES

Cases

Statutes

PATENT OWNER'S EXHIBIT LIST

Exhibit No	*Description*
2001	Declaration of Tom D. Milster, Ph.D.
2002	Curriculum Vitae of Tom D. Milster, Ph.D.
2003	Deposition transcript of José Sasián, January 22, 2021
2004	José Sasián, Introduction to Lens Design (2019)
2005	Peter Clark, "Mobile platform optical design," Proc. SPIE 9293, International Optical Design Conference 2017, 92931M (17 December 2014)
2006	Symmons and Schaub, *Field Guide to Molded Optics* (2016)
2007	G. Beall, "By Design: Part design 106 – Corner radiuses," *Plastics Today* (199)
2008	*Handbook of Optics*, 2nd ed., vol. 2 (1995)
2009	Declaration of José Sasián in IPR2019-00030
2010	Declaration of Marc A. Fenster in Support of Motion to Appear Pro Hac Vice
2011	Declaration of James S. Tsuei in Support of Motion to Appear Pro Hac Vice
2012	Deposition transcript of José Sasián, May 28, 2021

I. INTRODUCTION

As set forth below, Apple's reply fails to rebut the core arguments made in Corephotonics' response. Moreover, the reply is rife with technical misunderstandings, with unreliable or conclusory analysis, and with untimely new arguments. Grounds 2–4 of this IPR should be rejected.

II. GROUND 2 – OGINO IN VIEW OF BAREAU

A. Apple Fails to Demonstrate that the Proposed Design Is Manufacturable Using *Any* Technique

As explained in Corephotonics' response, Apple's combination of Ogino with Bareau rests on a lens design that cannot be manufactured. A lens that cannot be made cannot satisfy the limitations of the '897 patent claims to a "lens assembly" comprising "a plurality of lens elements." (Ex. 1001 at 8:22, 9:26–27.) And even if it could, no POSITA would be motivated to design such an impossible lens. Apple's reply suggests this argument "seems to rely on an implicit requirement of large-scale injection plastic molding." (Paper 14 at 9.) Apple's own expert has opined that Ogino's lens would "preferably be made of plastic via injection molding." (IPR2019-00030, Ex. 2009, Sasián Decl. at 69.)

But Apple's reply profoundly misses the point made in Corephotonics' response. The point of Corephotonics' response is that Apple's proposed design, with its edge thickness of 0.0394 mm, edge slope of 58.86°, center-to-edge ratio of 15.238, lack of oversizing, and sharp corners, cannot be successfully made *using any technique for lens manufacture*, whether it be injection molding of plastic (Ex. 2001, ¶¶ 60, 62, 77–78, 103–108, 112, 117, 121), injection molding of glass (*id.*, ¶¶ 60, 63, 103–108, 112, 117, 119, 120), grinding or polishing of glass (*id.*, ¶¶ 60, 63, 104–107, 110, 117, 119, 120), diamond turning (*id.*, ¶¶ 104, 107, 117, 120, 121), or any other technology (*id.*, ¶¶ 106–107, 117).

To rebut this evidence, it is not enough to say that Ogino is not limited to injection molded plastic, as Apple does, or to argue that these claims should not be limited to specific center-to-edge thickness ratios taught in the '897 patent specification. Rather, presented with such detailed evidence that the proposed lens is contrary to the teachings of Dr. Sasián's textbook, references that Apple itself relies on in its obviousness grounds, and the recognized limits of fabrication *using any technique*, it was incumbent on Apple to identify *some technique* that could be used to make the proposed lens, even in limited numbers and at great cost. Apple does not even attempt to do so, instead attacking

strawmen such as that Corephotonics argues the ’897 patent is limited to plastic injection molding or to mass production. (*See* Ex. 2012, Sasián Depo.at 121:7–123:21 (when asked if he had pointed to any technique other than injection molding of plastic that could be used to manufacture these lenses, Dr. Sasián could only point to a discussion of glass polishing used to make the spherical glass lenses cited in a different Apple IPR, which he acknowledged is not “the most appropriate technique” for making aspheric surfaces like those in Ogino or Chen, aside from a type of glass “correcting plate” used in large telescopes.))

B. Corephotonics’ Arguments Are Not Foreclosed by Limitations in Other Claims or by Unsuccessful Arguments in Another IPR

Apple suggests that it is irrelevant whether the proposed lens could actually be made, because the claims challenged under Ground 2 do not have a limitation for the L11/L1e ratio. (Paper 14 at 10–11.) That might be a persuasive argument if Apple were presenting a lens with L11/L1e of 4.0 or even 5.0, but Apple’s lens has a ratio of 15.238! And this ratio is just one of several features, including edge thickness, edge slope, lack of oversizing, and sharp corners that make the proposed lens design profoundly unmanufacturable.

Apple argues that Corephotonics’ argument is foreclosed by an argument it made against a POSITA combining Ogino with Beich in IPR2019-00030.

What Apple neglects to mention is that Apple argued the opposite position in that IPR and that the *Board rejected this argument from Corephotonics*, expressly finding that:

> Beich teaches that a lens designer should have a basic understanding of the manufacturing process, which would include the limits for fabricating lens elements in an optical lens assembly. . . . We are persuaded that the information conveyed in Beich would have been understood, known, and applied by the ordinarily skilled lens designer . . . .

(IPR2019-00030, Paper 32 at 18.) Moreover, Apple argues *in this very IPR* that a POSITA would have been motivated to apply Beich's teachings concerning center-to-edge thickness ratio when modifying Ogino. (Paper 2 at 47–52.) Apple cannot have it both ways, successfully invalidating one Corephotonics patent on the grounds that a lens designer would consider manufacturability and seeking to do the same for some claims in Ground 3 of this very IPR, but then arguing Corephotonics cannot make arguments based upon manufacturability with respect to Ground 2.

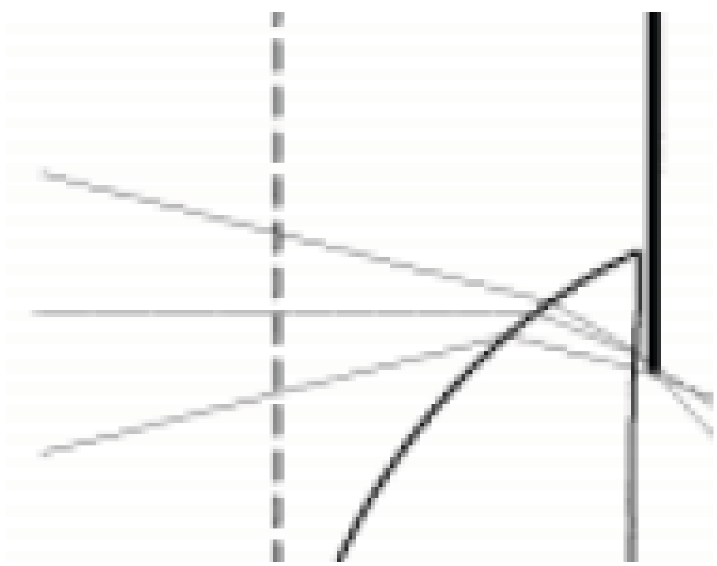
Moreover, even if Apple were to somehow change course, and argue a POSITA would not have been concerned with teachings such as those in Beich, Corephotonics manufacturability arguments for Ground 2 also rest on

Dr. Sasián's textbook, Exhibit 2004. (*See* Ex. 2001, Milster Decl., ¶¶ 106, 110, 114, 118.) This textbook is titled "Introduction to Lens Design" (Ex. 2004), which strongly suggests that its teachings on manufacturability are within the ken of a POSITA lens designer. As Dr. Sasián acknowledged, this textbook teaches that both glass *and* plastic lenses must avoid sharp corners to prevent chipping and other damage. (Ex. 2012, Sasián Depo.at 119:4–120:4.)

C. The Konno and Mercado Patents Do Not Show that the Proposed Design Is "Useful"

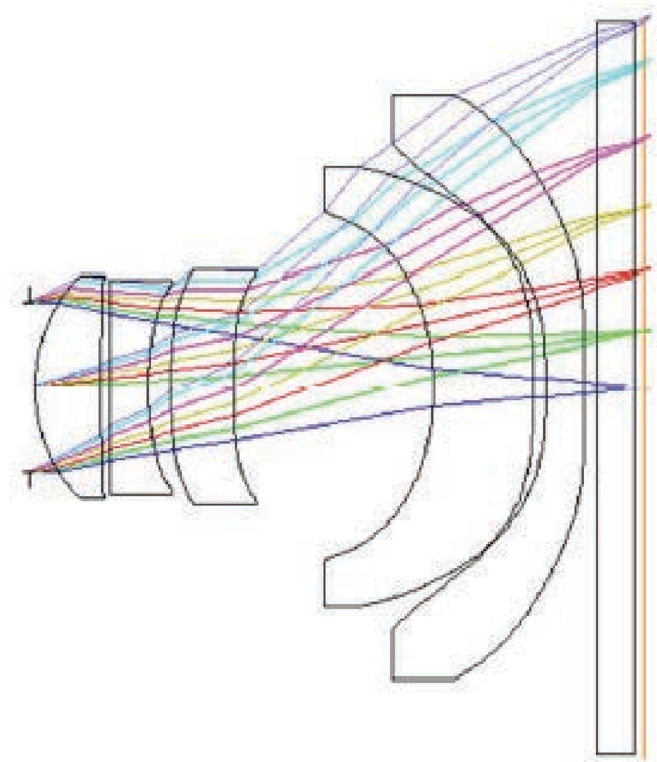
Apple suggests that lens manufacturability is not necessary in the art because of two published patents with purportedly "useful" lenses that purportedly fail to meet the requirements of manufacturability. (Paper 14 at 14–15.) But Apple's argument misunderstands these lens designs and the crucial way they differ from Apple's proposed lens. While these patents show drawings of first lenses that appear to have narrow edges and sharp corners, a careful look at the ray traces shows that no light rays that form the image actually pass through the part of the first lenses close to these edges:

(Ex. 1035, Fig. 11, excerpt enlarged; *see* Ex. 2012, Sasián Depo.at 111:18–112:19.)



(Ex. 1036, Fig. 13, excerpt enlarged; *see* Ex. 2012, Sasián Depo.at 116:14–117:16.)

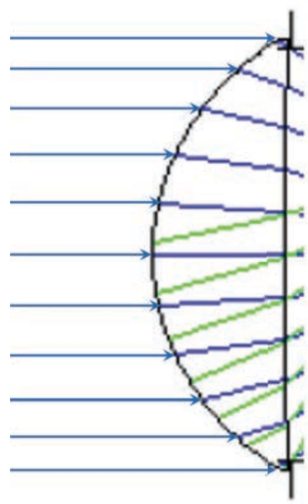
In other words, the outer portions of these lens elements are outside of the "clear apertures" where the lens shape matters to formation of the lens. (*See*, Ex. 2001, Milster Decl., ¶¶ 101, 102; Ex. 2012, Sasián Depo.at 109:14–23, 111:11–17, 112:11–19.) While lens design software may have drawn the lenses with these sharp edges, a POSITA would understand that these sharp edges are not necessary to the function of the lens and would not actually be present. This is confirmed by Dr. Sasián's own Zemax analysis of precisely the same lens (unmodified) from the Konno patent, which showed the first lens ending at the edge of the clear aperture and having a thick edge, not the sharp edge shown in the Konno figure Apple points to:



(IPR2020-00906, Ex. 1021, Sasián Decl. at 31; *see* Ex. 2012, Sasián Depo. at 108:17–109:13 (confirming this IPR2020-00906 declaration addresses the same Konno design as cited in the present IPR).) Dr. Sasián acknowledged this during his deposition. (Ex. 2012, Sasián Depo.at 113:7–114:9.) As Dr. Sasián further confirmed, a POSITA would understand that the plastic injection-molded lenses taught by Konno would actually have a flange for mounting, rather than the sharp edges depicted. (*Id.* at 115:3–24.) Dr. Sasián confirmed that the Mercado lens would likewise incorporate a flange and have

a shape different from that shown outside the clear aperture. (Ex. 2012, Sasián Depo.at 117:11–118:1.)

The situation with Apple's proposed lens is far different. As Corephotonics showed in its response, the rays that form the image in this proposed lens go all the way to the edge of the lens, and must do so to satisfy the claim elements, meaning that the clear aperture goes to the edge of the lens, and the lens must have the sharp edges to achieve the f-number of 2.8:



(Ex. 2001, Milster Decl., ¶¶ 96–97.)

In other words, the sharp edges in the figures from Konno and Mercado are artifacts of how the lens design software chose to draw the lenses outside the clear apertures, not features that would be present in a manufactured lens.

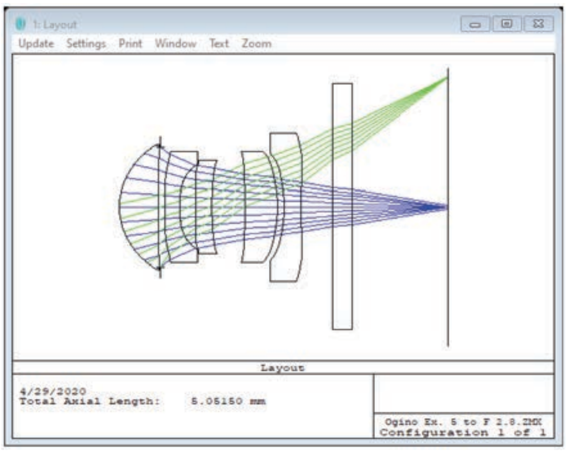
The unmanufacturable sharp corners in Apple's lenses, by contrast, must be present in the manufactured lens to satisfy the challenged claim elements.

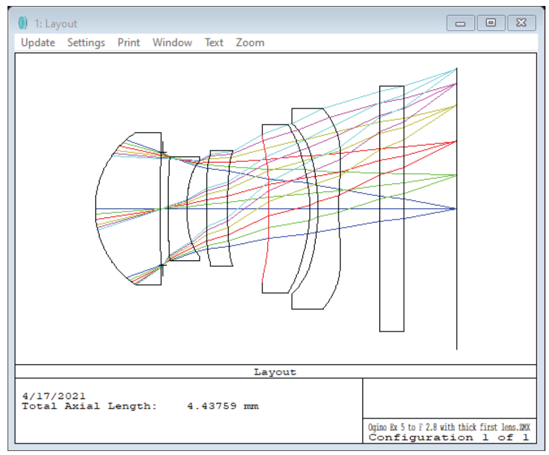
D. Apple Fails to Show the Preferred Embodiments Are Not "Finished" or Manufacturable

Apple tries to show that the Example 1 lens of the '897 patent is "not a finished lens, suitable for manufacturing." (Paper 14 at 17–18.) But it does not show evidence of any flaw in the lens that would prevent it from being manufactured using common techniques or from being a useful lens. Apple alleges that '897 patent Example 1 "is not desensitized" and "suffers from serious ghost images that are focused on the image plane." (Paper 14 at 18.) But as evidence for this, Apple cites only a single-sentence paragraph from Dr. Sasián's reply declaration, with the conclusory statement that these problems are present. (Ex. 1037, ¶ 22.) Dr. Sasián does not say how he knows or determined that these problems are present or how significant or "serious" these problems are. He does not mention whether these problems are present in the patent's other examples. He certainly does not show evidence that a POSITA would consider these problems serious. This opinion amounts to little more than an *ipse dixit* that "Corephotonics' own lens is bad," and it should be disregarded in its single-sentence entirety.

E. Apple's New Untimely Design Should Be Disregarded

As a last-ditch fallback, Apple offers a different way of combining Ogino with Bareau, presenting a lens design never mentioned in the Petition. (Paper 14 at 19–22.)





(Paper 14 at 19.) In creating this new lens, Dr. Sasián manually changed the thickness of the first lens element and performed steps in Zemax that turned off vignetting and that caused the location of the image plane to change, along with the conic constant of the first lens surface and 32 higher-order aspheric terms describing the lens surfaces. (Ex. 2012, Sasián Depo.at 113:7–114:9, 133:5–134:2; Ex. 1037 at 40.) In short, this is a new lens design and a new purported combination of Ogino with Bareau.

A complex lens design can have numerous problems that are not apparent to a lay reader and cannot be demonstrated without expert testimony, as evidenced by the 25 pages of expert testimony that Corephotonics' expert devoted to Ground 2 as presented in the petition. (Ex. 2001 at 36–61.) The rules of IPRs, directed as they are to ensuring proceedings finish within the statutory deadlines, do not permit Corephotonics to marshal such evidence in response to a new design presented in reply. Accordingly, Apple's reply was an opportunity for it to attempt to show that Corephotonics' criticisms of the Ground 2 design presented in the petition were invalid, not an opportunity to use Corephotonics' response as a roadmap for creating a new invalidity theory that Corephotonics is prevented by the rules from rebutting. *See Intelligent Bio-Sys., Inc. v. Illumina Cambridge Ltd.*, 821 F.3d 1359, 1369 (Fed. Cir. 2016) ("It is of the utmost importance that petitioners in the IPR proceedings adhere to the requirement that the initial petition identify 'with particularity' the 'evidence that supports the grounds for the challenge to each claim.' 35 U.S.C. § 312(a)(3)."); *Wasica Fin. GmbH v. Contl. Automotive Sys., Inc.*, 853 F.3d 1272, 1286 (Fed. Cir. 2017) ("Rather than explaining how its original petition was correct, Continental's subsequent arguments amount to an entirely new theory of prima facie obviousness absent from the petition. Shifting

arguments in this fashion is foreclosed by statute, our precedent, and Board guidelines." *Ariosa Diagnostics v. Verinata Health, Inc.*, 805 F.3d 1359, 1367 (Fed. Cir. 2015) (holding that "a challenge can fail even if different evidence and arguments might have led to success"); *see General Plastic Industrial Co., Ltd. v. Canon Kabushiki Kaisha*, IPR2016-01357, Paper 16 at 9 (PTAB Nov. 14, 2016) (recognizing the injustice of petitioner being permitted to wait until after seeing patent owner's arguments and then craft a new invalidity argument in response).

III. GROUND 3 – OGINO IN VIEW OF BAREAU AND KINGSLAKE

A. Apple Provides No Articulable Motivation for Changing the Image-Side Surface from Concave to Convex

Apple compares Dr. Sasián's change of the image-side surface of Ogino's first lens from concave to convex to the change he made to Ogino's second lens from biconcave to meniscus in IPR2018-01140. (Paper 14 at 22–23.) But the differences are substantial. While Corephotonics argued against Apple's motivation to modify the Ogino second lens based upon Chen II in IPR2018-01140, at least Apple presented a cognizable theory of motivation for the change. Apple presented a reference, Chen II, that contained a meniscus lens. (IPR2018-01140, Paper 37, Final Written Decision at 33.) Its expert opined

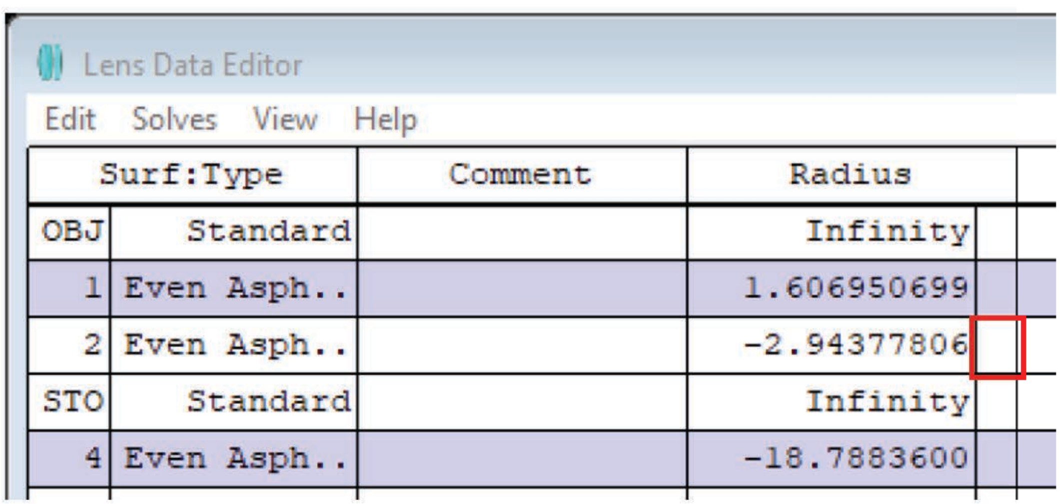
that a POSITA looking at Chen II would recognize that its meniscus second lens provided specific advantages that address specific purported deficiencies in Ogino's design. (*Id.* at 34.) In other words, there was a specific reason, based upon specific disclosures in Chen II, for changing Ogino to satisfy the claim limitation in question. In light of these facts, the Board rejected Corephotonics arguments that were based on Ogino's teaching of the benefits of the biconcave second lens. (*Id.* at 35.) Specifically, the Board argued that a POSITA could weigh the benefits of the biconcave second lens taught by Ogino against the benefits of a meniscus second lens purported shown in Chen II. (*Id.* at 36.) While Corephotonics disagrees with the conclusion, it was at least grounded in some way, however tenuous, on a lens that was shown in Chen II.

Apple would take from this decision by the Board in IPR2018-01140—that it would have been obvious to change a specific lens surface from concave to convex based upon Chen II—the conclusion that all changes of lens shape between convex and concave are *per se* obvious. The Board made no such finding.

Here, Apple proposes changing the image side surface of Ogino to convex, but it does not cite to a single reference that has such a convex image side

surface or to *anything* in the prior art that would suggest that changing this surface from concave to convex would provide benefits. For that matter, Apple *does not identify any benefits* that actually result from this change, whether those benefits were taught in the art or not.

Moreover, Apple's reply and the declaration of Dr. Sasián fail to explain how Dr. Sasián even arrived at the convex shape. As explained in Corephotonics' response, the Zemax output in Dr. Sasián's declaration shows that the radius of curvature for the image-side surface of the first lens in his modification to Ogino was *fixed* to have a value of -2.94377806, and thus the lens was *fixed* to have a convex surface (a negative radius for the image-side surface meaning it is convex):



Lens Data Editor

Edit Solves View Help

Surf:Type		Comment	Radius	
OBJ	Standard		Infinity	
1	Even Asph..		1.606950699	
2	Even Asph..		-2.94377806	
STO	Standard		Infinity	
4	Even Asph..		-18.7883600	

(Ex. 1003, Sasián Decl. at 111; Ex. 2003, Sasián Depo.at 49:20–50:16; Ex. 2001, Milster Decl., ¶¶ 136–137.) This negative radius of curvature was "most likely" produced using an earlier Zemax optimization that he did not explain in his original declaration and that he could not recall any details of during his deposition. (Ex. 2003, Sasián Depo. at 50:18–53:9.) Dr. Sasián's reply declaration sheds no further light on how or with what steps he obtained the negative radius of curvature for the image-side surface of the first lens, beyond the vague statement that he "experiment[ed] with [sic] to see if a smaller f-number would also have been attainable for Example 5." (*See* Ex. 1037, ¶¶ 31–32.)

B. Dr. Sasián's Zemax Analysis Remains Unreliable

Dr. Sasián's reply declaration and deposition raise other questions about the reliability of his Zemax analysis concerning this modification to Ogino. For example, Corephotonics noted in its response that Dr. Sasián reported multiple inconsistent values for the f-number in this modification. (Ex. 1003 at 108 (giving both "2.12" and "2.45" as values for the f-number).) In an apparent attempt to clarify the issue, Dr. Sasián's reply declaration purports to provide the true values of f-number (and of the related entrance pupil diameter ENPD). (Ex. 1037, ¶ 33, Paper 14 at 26.) But rather than provide a screenshot of Zemax showing the values, as he repeatedly did for other values throughout

his declarations, he testified that he manually typed these "correct" values into his reply declaration by hand, as evidenced by the use of a font that Zemax does not use. (Ex. 2012, Sasián Depo.at 101:1–15.) Even more strangely, Dr. Sasián testified that when he manually typed the value of f-number 2.45 into his declaration, he was basing it on his memory of typing that number into Zemax a year earlier, rather than on any specific number displayed by Zemax. (*Id.* at 104:2–25.) While the difference between an f-number of 2.12 and 2.45 may not matter to the '897 claim limitations, it is relevant to the motivation to make Dr. Sasián's modifications, as nothing in the record suggests a motivation to reduce f-number to 2.12. More generally, the failure to accurately explain how he did this Zemax work and what his results were further calls into question his claim that a POSITA would have been motivated to change the image-side surface from concave to convex.

Nothing about a smaller f-number necessarily requires, or even benefits from, a convex image-side surface. Apple certainly provides no evidence of a connection. At most and giving him every benefit of the doubt, Dr. Sasián's declarations show that a highly skilled paid expert, with enough experiments at ways to create a lens with reduced f-number, might arrive at some example that meets the claim limitation that is otherwise missing from the design. Put

another way, it shows that a highly skilled lens designer whose job it was to turn Ogino's lens into a lens that meets the challenged claims *could* do so.

This does not show that a POSITA *would* have changed the surface from concave to convex or that the POSITA would have seen any *motivation* to make that change. Apple points to no such motivation anywhere in the prior art. Apple's evidence falls far short of what is required to show obviousness.

IV. GROUND 4 – CHEN IN VIEW OF IWASAKI AND BEICH

A. The Proposed Combination Is Not Manufacturable

Corephotonics' response explained the serious limitations in manufacturing injection-molded lenses that a POSITA would understand make the modified lens that Apple proposes—with a first lens that is only thousandths of a millimeter larger than the aperture stop—unmanufacturable. (Paper 12 at 63–68.) In response, Apple argues that it does not matter whether a lens could actually be manufactured, because "these manufacturing considerations are not included in claims 16 or 30" and because "a lens designer would not have been bound by these specific manufacturing considerations regardless of the purpose of the lens design." (Paper 14 at 28.)

This dismissal of manufacturing concerns is inconsistent with the requirements of the claims, with what a POSITA would have understood, and

with Apple's own stated motivation for modifying the Chen lens. Apple's petition stated that Chen example 1 "would preferably have been manufactured via injection molding" and gives that fact as a reason for combining with Beich, a "polymer injection molding reference[]." (Paper 2 at 68.) Apple's reply does not dispute that its proposed combination uses injection molded plastic. Apple's reply also does not dispute that any of the limitations of manufacturing tolerances for injection molding plastic, such as the tolerances for diameter, surface displacement, or rounding of corners are real or argue they are different than what is stated in the patent owner's response. (*See* Paper 12 at 66–67.) Apple also does not dispute that a first lens with semi-diameter less than the stop semi-diameter will lead to highly undesirable light leakage and a hazy image. (*See* Paper 12 at 66.)

As a POSITA would recognize, claims 16 and 30 are all about manufacturability considerations. The limitation that each claim adds is the requirement that the first lens have a ratio L11/L1e less than 3. (Ex. 1001, '897 patent at 9:22–25, 10:34–37.) As the '897 patent specification explains, this requirement is *entirely* about manufacturability. (Ex. 1001, '897 patent at 2:41–50.) More generally, the claims of the '897 patent are directed to "lens as-

sembl[ies]" comprising a "plurality of lens elements," i.e. to real physical objects that can be made in the real world. (*E.g.*, Ex. 1001, '897 patent at 8:22, 9:26–27. Apple does not suggest—and a POSITA would not understand—that the '897 patent claims are directed to non-physical objects that can be simulated in a computer, but not actually made using the techniques known in the art. A POSITA reading claims 16 and 30 and the related discussion in the '897 patent specification would understand that they are directed to manufacturable lenses, not to lenses that happen to meet the L11/L1e ratio requirement but are completely unmanufacturable for other reasons.

More significantly, Apple's dismissal of manufacturability is contrary to the very motivation that its petition relied upon for combining Chen and Iwasaki with Beich. As the petition stated, "a POSITA looking to implement optical element specifications using injection molding methods would look to Beich for guidance on limitations and parameters that affect lens manufacturability." (Paper 2 at 67.) The very premise of Apple's obviousness theory for these claims is that the POSITA *is* concerned with making the lens manufacturable and *for that very reason* is looking to Beich. To suggest that the POSITA would not be concerned by the obvious and serious defects in the

manufacturability of the proposed lens explained in Corephotonics' response runs contrary to the core logic of Apple's obviousness theory.

The most basic problem with manufacturability of the proposed lens—the problem that the lens semi-diameter is specified as only 0.004 mm larger than the stop, but that manufacturing tolerance for the lens diameter is ±0.020 mm—is a problem that is apparent from Beich, which recites exactly that limitation on the precision of the lens diameter in injection molding plastic. (Ex. 1007 at 7.) Based on the teachings of Beich alone, a POSITA would understand that setting the diameter of the first lens of Chen small enough to satisfy the Beich Center Thickness to Edge Thickness Ratio teaching will lead to lenses that *leak light* in the gap between the lens and the aperture stop, i.e., to bad lenses. The POSITA would not be motivated to use a design that would lead to such defective lenses.

Notably, this situation is different from the situation in IPR2019-00030, where Apple relied upon the same rules of thumb from Beich. There, Corephotonics pointed out that other lens elements of the proposed design violated other rules of thumb from Beich, and argued that meant that a POSITA would not have looked to Beich's rules of thumb for the L11/L1e ratio. The Board rejected that argument, saying that a POSITA would look to supply a value

not supplied by the Ogino reference, even if other values in Ogino violated Beich's rules of thumb. (IPR2019-00030, Paper 32 at 46.) Here, however, the problem is not that *different* parameters in Chen violate Beich's rules. Rather, the problem is that the very parameter that Apple bases on one of Beich's rules, the first lens diameter, leads to a design that is plainly not manufacturable under Beich's rule that *specifically addresses lens diameter*, i.e. its "±0.020 mm" lens diameter tolerance. A POSITA looking to Beich's rules of thumb would not choose a lens diameter is inconsistent with the very teaching on tolerances for lens diameter set forth in those rules.

B. Dr. Sasián's Calculations Are Contrary to the Disclosures of the '897 Patent and Unreliable

Apple also dismisses Corephotonics' arguments concerning manufacturability on the grounds that the lenses in the '897 patent purportedly fail to meet those criteria of manufacturability. But the calculations from Dr. Sasián that Apple relies on are contrary to the teachings of the '897 patent and unreliable.

The '897 patent provides three detailed examples of lens assemblies, and identifies the first lens elements in each of these assemblies as elements 102, 202, and 302, respectively. (Ex. 1001, '897 patent, Figs. 1A, 2A, 3A.) The

specification supplies values of the L11/L1e ratio for each of these three examples. (Ex. 1001, '897 patent at 2:43–50.) In other words, the lens for the second example (202) satisfies the limitation of claims 16 and 30, with a value for L11/L1e of 2.916. The lenses of the first and third examples do not satisfy this limitation, but rather satisfy different, less demanding ratios that the specification provides as examples. (*Id.* at 2:43–48.)

Dr. Sasián's reply declaration gives very different values for L11/L1e, saying that the *first example* is the only one with a ratio less than 3 (equal to 2.99238 according to Dr. Sasián) and that the second example has a ratio of 3.049, i.e. greater than 3. (Ex. 1037, ¶¶ 39–41.) In his deposition, Dr. Sasián testified that *he was unaware that the patent provided values for these ratios or that his values were different from the patent's*:

> Q. So the numbers in the patent are a little different than the numbers that you calculated. In particular, for Example Number 2, according to paragraph 40 of your declaration, you calculated an L11/L1e ratio of 3.049, whereas the patent says that ratio is 2.916; would you agree?
>
> A. Could you please tell me the column and the line number on the –

Q. In the patent? Yeah, so the number I'm referring to, 2.916, appears in Column 2, line 48.

A. Okay. Thank you. Yeah, I see there is a difference.

Q. Prior to the last few minutes, were you aware of this difference between the numbers that you gave for the ratio in your declaration and the number given for the ratio in the patent itself?

A. No, I wasn't aware of the difference.

(Ex. 2012 at 88:13–89:15.) The fact that Dr. Sasián did not even know that he was providing numbers that differed from those provided in the patent, let alone try to explain the discrepancy, is sufficient to render his conclusions unreliable.

A further reason to doubt Dr. Sasián's numbers for the L11/L1e calculations is that we have no way of checking whether he correctly entered the greater than 100 decimal numbers, containing hundreds of digits, that make up the lens prescription tables supplied in tables 1–6 of the '897 patent. (Ex. 1001, '897 patent cols. 4, 6–7.) As discussed above, Dr. Sasián has acknowledged making at least one "clerical error" relating to the f-number and entrance pupil diameter he calculated in Zemax. (Ex. 2012, Sasián Depo.at 97:1–98:3.) He also has made at least one known error in entering lens prescription

data into Zemax in a related IPR brought by Apple against Corephotonics, entering the Abbe number from the wrong lens element in a given row of the lens prescription. (*See* IPR2020-00906, Paper 16 at 31; IPR2020-00906, Ex. 2015, ¶ 62.)

A similar data entry error may explain the discrepancy between Dr. Sasián's values for L11/L1e and the values provided in the patent. But, we have no way of checking Dr. Sasián's data entry, because he declined to provide screen captures of his lens prescription data from Zemax for these L11/L1e ratio calculations in his declaration, even though he had included precisely such screen captures of lens prescription data for his other Zemax analyses. (*Contrast* Ex. 1037 at 37, 40 *with id.* at 41–43.) As Dr. Sasián acknowledged in his deposition, this deprives Corephotonics of any way of checking this analysis from his reply declaration. (Ex. 2012, Sasián Depo.at 84:7–85:2.)

Even if we assume that Dr. Sasián entered all the data from the '897 patent tables correctly, the other problem with his calculations is that they are based upon the lens diameter values in the patent tables, which are rounded to only two digits of precision (see right-most column):

TABLE 3

#	Comment	Radius R [mm]	Distances [mm]	Nd/Vd	Diameter [mm]
1	Stop	Infinite	−0.592		2.5
2	L11	1.5457	0.898	1.53463/56.18	2.6
3	L12	−127.7249	0.129		2.6
4	L21	6.6065	0.251	1.91266/20.65	2.1
5	L22	2.8090	0.443		1.8
6	L31	9.6183	0.293	1.53463/56.18	1.8
7	L32	3.4694	1.766		1.7
8	L41	−2.6432	0.696	1.632445/23.35	3.2
9	L42	−1.8663	0.106		3.6
10	L51	−1.4933	0.330	1.53463/56.18	3.9
11	L52	−4.1588	0.649		4.3
12	Window	Infinite	0.210	1.5168/64.17	5.4
13		Infinite	0.130		5.5

('897 patent, Table 3 (from the prescription for the second example embodiment).) Dr. Sasián explained how relying on this rounded value of diameter could explain the discrepancy:

> Q. So I think you pointed out that the lens diameter values given in the lens prescription tables of the patents are only provided with a single digit after the decimal point?
>
> A. Yes.
>
> Q. So would one explanation for the difference be that the calculation of L11/L1e that resulted in the values in Column 2 of the patent used diameters that weren't exactly the values shown in the tables but simply round to be the values in the table?

> A. Well, rounding could be the answer. Yes, it could be a rounding issue.
>
> Q. So to speak concretely about Example 2 from the patent, in Table 3, the first and second surfaces of the first lens are listed as having a diameter of 2.6, but if the -- and that's what you used to calculate the ratio in your declaration. But if the lens diameter were a little bit less than 2.6 but greater than 2.55, somewhere in there, you might get the centered-edge-thickness ratio that's reported in Column 2 of the patent?
>
> A. Yeah, that would be the case.

(Ex. 2012, Sasián Depo.at 90:17–91:14.)

Apple's reply concludes that '897 patent example 2 has a ratio L11/L1e that is greater than 3.0 in the third decimal place (Paper 14), but that rests on calculation that uses a value for diameter with only two decimal places. This is not a reliable calculation. A POSITA would understand that the values given in lens prescription tables are rounded versions of numbers that were calculated using lens software that maintains far greater precision internally:

> Q. Okay. So the internal calculations in ZEMAX are done with 12 or more digits of precision; is that right?
>
> A. I believe so.

> Q. So would somebody reading a patent, like the ’897 patent, with a lens prescription in it expect that that lens prescription was created using software that internally used 12 or more digits of precision, and then, when the lens prescription was transcribed into the patent, the numbers calculated by the lens design software were rounded to be fewer digits of precision?
>
> A. Yes. That could happen. And in a previous deposition I had, there was a discrepancy, and I pointed out that likely it was due to rounding the number.

(Ex. 2012, Sasián Depo.at 93:11–94:9.) A POSITA looking to understand what the L11/L1e ratio is for its Example 2 lens would look to the value 2.916 expressly provided with four digits of precision at line 2:48, not the far less precise value computed by Dr. Sasián, relying on the imprecise values provided for the lens diameter.

Using the correct value of L11/L1e = 2.916 for Example 2, we see that it comfortably satisfies L11/L1e < 3.0. Importantly, Example 2 also provides the manufacturing tolerances that Apple’s proposed lens fails to satisfy. Table 3 specifies that the stop has a diameter of 2.5 mm, while the first lens element has a diameter of 2.6 mm. (Ex. 1001, Table 3.) This implies a lens semi-diam-

eter approximately 0.05 mm greater than that of the stop. By comparison, Apple's proposed lens has a semi-diameter only 0.004 mm greater than the stop. (Paper 12 at 66; Ex. 2001, Milster Decl., ¶ 146), a margin more than 10 times smaller than that in '897 patent Example 2. This difference is critical, in light of Beich's teaching that the lens diameter tolerance for injection molding is ±0.020 mm (i.e., semidiameter of ±0.010 mm). (Ex. 1007 at 7.) A lens design like '897 patent Example 2, with a margin of 0.05 mm between the semi-diameter of the lens and the stop, can tolerate errors in the lens diameter of ±0.010 mm. A lens design with a margin of only 0.004 mm cannot.

Likewise, '897 patent Example 2 has a lens with a diameter 2.6 mm, compared to its clear aperture (defined by the stop) of 2.5 mm. In other words it is oversized by approximately (2.6 mm – 2.5 mm) / 2.5 mm = 4%. This is consistent with the requirement known in the art to oversize lenses by around 4–10%. (Ex. 2001, Milster Decl., ¶ 149; Ex. 2006, Symmons at 103.) By contrast, the lens proposed by Apple cannot even be oversized by 1% without failing to satisfy the limitations of claims 16 and 30. (Ex. 2001, Milster Decl., ¶¶ 145–150.)

For all of these reasons, a POSITA would recognize that '897 patent Example 2 describes a lens that is manufacturable, using injection molding of

plastic. That same POSITA would recognize that Apple's proposed modification to Chen, needed to satisfy the limitations of claims 16 and 30, is not manufacturable, for reasons explained in Beich and in the other evidence cited in the patent owner's response. (Paper 12 at 63–68.)

V. CONCLUSION

Corephotonics respectfully requests that the Board affirm the patentability of the claims challenged under Grounds 2–4.

Respectfully submitted,

Dated: June 11, 2021

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CERTIFICATE OF WORD COUNT

I certify that there are 5,577 words in this paper, excluding the portions exempted under 37 C.F.R. § 42.24(a)(1).

/Neil A. Rubin/
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CERTIFICATE OF SERVICE

I hereby certify that "Patent Owner's Sur-Reply" was served on June 11, 2021

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UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.
Petitioner,

v.

COREPHOTONICS, LTD.,
Patent Owner.

IPR2020-00878
U.S. Patent No. 10,330,897 B2

PETITIONER APPLE INC.'S NOTICE OF APPEAL

via E2E
Patent Trial and Appeal Board

via Hand Delivery
Director of the United States Patent and Trademark Office
c/o Office of the General Counsel, 10B20
Madison Building East
600 Dulany Street
Alexandria, VA 22314

via CM/ECF
United States Court of Appeals for the Federal Circuit

Pursuant to 28 U.S.C. § 1295(a)(4)(A), 35 U.S.C. §§ 141(c), 142, and 319, and 37 C.F.R. §§ 90.2(a), 90.3, and Federal Circuit Rule 15(a)(1), Petitioner Apple Inc. ("Petitioner") provides notice that it appeals to the United States Court of Appeals for the Federal Circuit from the Final Written Decision of the Patent Trial and Appeal Board ("Board") entered November 2, 2021 (Paper 29), and from all underlying and related orders, decisions, rulings, and opinions regarding U.S. Patent No. 10,330,897 B2 ("the '897 patent") in *Inter Partes* Review IPR2020-00878.

In accordance with 37 C.F.R. § 90.2(a)(3)(ii), the expected issues on appeal include, but are not limited to: the Board's error(s) in determining that claims 3, 8, 16, 19, 24 and 30 are not unpatentable, and all other issues decided adversely to Petitioner in any orders, decisions, rulings, or opinions.

Pursuant to 35 U.S.C. § 142 and 37 C.F.R. § 90.2(a), a copy of this Notice is being filed with the Director of the United States Patent and Trademark Office and with the Patent Trial and Appeal Board. In addition, a copy of this Notice and the required docketing fees are being filed with the Clerk's Office for the United States Court of Appeals for the Federal Circuit via CM/ECF.

Respectfully submitted,

Dated: January 4, 2022

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CERTIFICATE OF FILING

The undersigned hereby certifies that, in addition to being electronically filed through PTAB E2E, a true and correct copy of the above-captioned PETITIONER APPLE INC.'S NOTICE OF APPEAL is being filed by hand with the Director on January 4, 2022, at the following address:

Director of the United States Patent and Trademark Office
c/o Office of the General Counsel, 10B20
Madison Building East
600 Dulany Street
Alexandria, VA 22314

The undersigned also hereby certifies that a true and correct copy of the above-captioned PETITIONER APPLE INC.'S NOTICE OF APPEAL and the filing fee is being filed via CM/ECF with the Clerk's Office of the United States Court of Appeals for the Federal Circuit on January 4, 2022.

Respectfully submitted,

Dated: January 4, 2022

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CERTIFICATE OF SERVICE

Pursuant to 37 C.F.R. § 42.6, this is to certify that a true and correct copy of the foregoing "Petitioner Apple Inc.'s Notice of Appeal" was served on the Patent Owner Corephotonics, Ltd. as detailed below:

Date of service	January 4, 2022
Manner of service	Electronic Service by E-mail: – nrubin@raklaw.com – jchung@raklaw.com – mfenster@raklaw.com – jtsuei@raklaw.com
Documents served	**Petitioner Apple Inc.'s Notice of Appeal**
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UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

APPLE INC.
Petitioner

v.

COREPHOTONICS, LTD.,
Patent Owner

Case IPR2020-00878
U.S. Patent No. 10,330,897

PATENT OWNER'S NOTICE OF APPEAL

Office of the General Counsel
United States Patent and Trademark Office
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Alexandria, VA 22313-1450

Submitted Electronically via the PTAB E2E System

Pursuant to 35 U.S.C. §§ 141, 142, and 319, and in accordance with 37 C.F.R. §§ 90.2-90.3, Patent Owner Corephotonics, Ltd. ("Corephotonics") appeals to the United States Court of Appeals for the Federal Circuit from the Final Written Decision of the Patent Trial and Appeal Board ("Board") entered on November 2, 2021, in IPR2020-00878 (Paper No. 29) ("Final Written Decision"), and from all underlying findings, determinations, rulings, opinions, orders, and decisions regarding the inter partes review of U.S. Patent No. 10,330,897 (the "'897 patent").[1]

In accordance with 37 C.F.R. § 90.2(a)(3)(ii), Corephotonics states that the issues on appeal may include, but are not limited to: the Board's determination that claims 2, 5, 6, 18, 21–23 of the '897 patent have been shown to be unpatentable; the Board's consideration of the expert testimony, prior art, and other evidence in the record; and the Board's factual findings, conclusions of law, or other determinations supporting or related to those issues, as well as all other issues decided adversely to Corephotonics in any orders, decisions, rulings, and opinions.

This Notice of Appeal is being e-filed with the Clerk's Office for the United States Court of Appeals for the Federal Circuit, along with payment of the required docketing fees. In addition, a copy of this Notice of Appeal is being filed simultaneously with the Patent Trial and Appeal Board.

[1] Petitioner Apple Inc. has also filed a notice of appeal from this Final Written Decision on this day, which was assigned Federal Circuit Docket # 22-1325.

Respectfully submitted,

Dated: January 4, 2022

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CERTIFICATE OF SERVICE (37 C.F.R. § 42.6(e)(1))

The undersigned hereby certifies that the above document was served on January 4, 2022, by filing this document through the Patent Trial and Appeal Board End to End System as well as delivering a copy via electronic mail upon the following attorneys of record for the Petitioner:

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A copy of this Notice of Appeal was also sent on January 4, 2022 by United States Postal Service Priority Mail Express to the United States Patent and Trademark Office at the following address:

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